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INTEGRATED WETLAND SYSTEM (IWS) FOR WASTEWATER TREATMENT AND RECYCLING

FOR THE POORER PARTS OF THE WORLD WITH AMPLE SUSHINE

BASIC MANUAL

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Prefatory

A number of strategic issues were discussed in the Agenda-21 in relation to environmental problems of the third world cities. It emphasized the importance of waste management and recycling and the need for institutionalizing participatory approach. It also identified the local urban authorities as the key agents of change.

This manual on integrated wetland system project for wastewater treatment and recycling is particularly aimed at providing a low-cost, ecologically balanced and community linked option for the poorer cities of the world with ample sunshine. It is expected to be used, in the main, by engineers, planners, local urban authorities, environmental groups and decision makers for a broad understanding of the IWS projects.

A manual of the present size cannot address to every details of the wide range of issues and parameters of project implementation. None the less, an attempt has been made to prepare a primer on most of the major issues and linkages related to decision making which can effectively lead to location specific studies on feasibility of IWS projects.

Dhrubajyoti Ghosh Ph.D.
Calcutta 1995

ACKNOWLEDGEMENT

The work of writing this manual draws heavily from the farmers of the east Calcutta wetlands who are engaged in using the city's wastewater in fisheries and agriculture for many years and retain the knowledge in an oral tradition. Mr Debatosh Biswas and Mr Sivabrata Ghatak assisted me on technical matters and Ms Dipanjana Maulik rendered useful help on computer key board. Ms Susmita Sen read the manuscript several times and improved it.

15 January 1995

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Seldom is available an alternative knowhow that is less capital intensive and can yet get the best desired benefits. This is particularly true where the search is for an ecologically acceptable choice. The ***integrated wetland system*** *project is one of such none-too-frequent examples in environmental protection and development management where benefits are achieved at a lower cost and which is in perfect harmony with the environment. It is a system that sets the river free from domestic contaminants and can at the same time recover the wastewater nutrients with remarkable efficiency to grow fish. The system costs less than other technologies for treating sewage and recycling waste. The world's largest example of such a system is seen in the wetlands to the east of Calcutta which have been working effectively for more than fifty years. From these wetlands we are learning, examining, and adopting.*

1. CONTEXT

1.1 BACKGROUND

Untreated municipal sewage is a serious cause of environmental concern and occasionally has been found to contribute major pollution load to the river in which it is disposed of. Cost of installation and maintenance of conventional wastewater treatment plants is disproportionately high. The meagre amount of fund available for municipality in most of the economically weaker countries renders the plants non-viable. Disorders in conventional sewage treatment plants are frequent. Whereas, wetlands in urban periphery are natural receptacles for wastewater which harness the nutrients available in waste through fisheries and agriculture.

Planning for municipal sanitation therefore, in poorer countries in general and in the areas with a hot climate in particular, will have to emerge from two basic lessons that have become apparent through the trial of time.
These lessons are :

* Sewage treatment plants are essentially non-viable because of the high cost of installation , prohibitive operational cost and repeated plant breakdowns.

* Whereas, municipal effluent is a nutrient pool which can effectively be used to grow fish and for irrigating agriculture and plantations.

These lessons corroborate the observations made in a World Bank /IDRC report on lowcost sanitation technology options which summarised the experiences in developing countries .

It has stated inter alia:

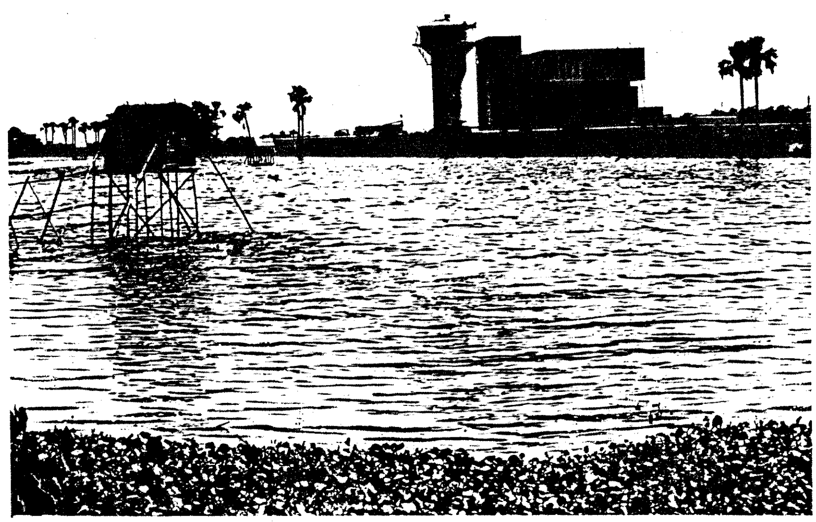
* 'universal' solution of sewage treatment plants does not reach more than 6.5% of the people in developing countries.

* resource recovery practices through fish culture, algae production and aquatic plants/energy production are new and promising technologies that radically change the context of urban sanitation.

During the same time the wetlands gained significance as a wastewater treatment ecosystem. In the North, 'constructed wetlands' are one of such non-conventional options which are gaining ascendancy. Improvement of wastewater quality is ensured by wetland systems dominated mainly by aquatic macrophytes. These wetland systems are not intended to ensure nutrient recovery, another prominent wetland function and their system economics do not include any resource recovery component in calculating the cost-effectiveness of the option.

Entirely in a different setting, in the South, a tradition of using wastewater in ponds for growing fish is known to exist in many places. These wetland systems work effortlessly with the help of a local wisdom which is mostly recorded in oral traditions. The Calcutta wetlands sustain the biggest ensemble of such fish ponds in the world. The local farmers, unaware of the function of wastewater treatment, are excellent performers in recovering wastewater nutrients to grow food through a viable and self-reliant technology option. Scientific studies, since 80's, revealed the high quality performance of these fish ponds in improving wastewater quality. In essence, they behave, in many ways, as stabilisation ponds for reducing biological and chemical toxicity of urban wastewater. The little educated farmers of the South recognized the natural functions and integrated multiple use of wetlands more appropriately and strengthened the economic viability of the wetland system option.

Calcutta wetlands are conserved as an urban facility for treating the city's wastewater and recycling it in fisheries and agriculture.



1.2 SCOPE OF THE MANUAL

Immediate limitation of a knowledge being held in an oral tradition is its inability to ensure fluent replicability. The present manual is an attempt to bridge this gap and provides basic technical information for the users of this **integrated wetland system** option. Engineering contents of this manual are based on the studies carried out in the Calcutta wetlands and information collected from Resource Efficient Stabilisation Tank projects executed in some of the cities of West Bengal under the Ganga Action Plan of the Government of India. These projects have been designed on the basis of Calcutta wetland experience and include the component of institutionalizing local people's participation at various stages of planning, construction and running the projects. In some areas available information are either deficient or are empirical in nature. This manual is not aimed at promoting integrated wetland systems as the only alternative for wastewater treatment and resource recovery but it campaigns in favour of the option as self-reliant and viable for the cities in the poorer parts of the world with ample sunshine.

From the existing variations observed in wetland-based systems of recycling city sewage a set of alternatives for the IWS project type and size emerges and is shown in (figure - 1). Basically the options are of two types (figure - 2):

* Flow-Through System (wastewater treatment as primary objective)
* Abstracted Flow System (resource recovery as primary objective)

In the 'flow-through system' the entire wastewater is transported through a pre-treatment system and is then detained in the recycling ponds for further treatment and for growing fish. Subsequently the effluent from the recycling ponds is used for irrigation in downstream areas.

Alternatively, in the 'abstracted flow system' wastewater is abstracted from the outfall channel or receptacle stream and is used for growing fish or for irrigation or both. In this case the user can draw the wastewater as and when required. A large area of the Calcutta wetlands consists of fish ponds of this kind.

The present manual is primarily intended to provide guidelines for the 'flow-through system' because it needs less land to ensure adequate wastewater treatment and is particularly effective where cost of land is high. The 'flow-through system' can be divided into two types, namely :

* minimum area system or low-cost system

* large area system

In the 'minimum area system' the emphasis is on wastewater treatment and

SYSTEM TYPE AND SIZE

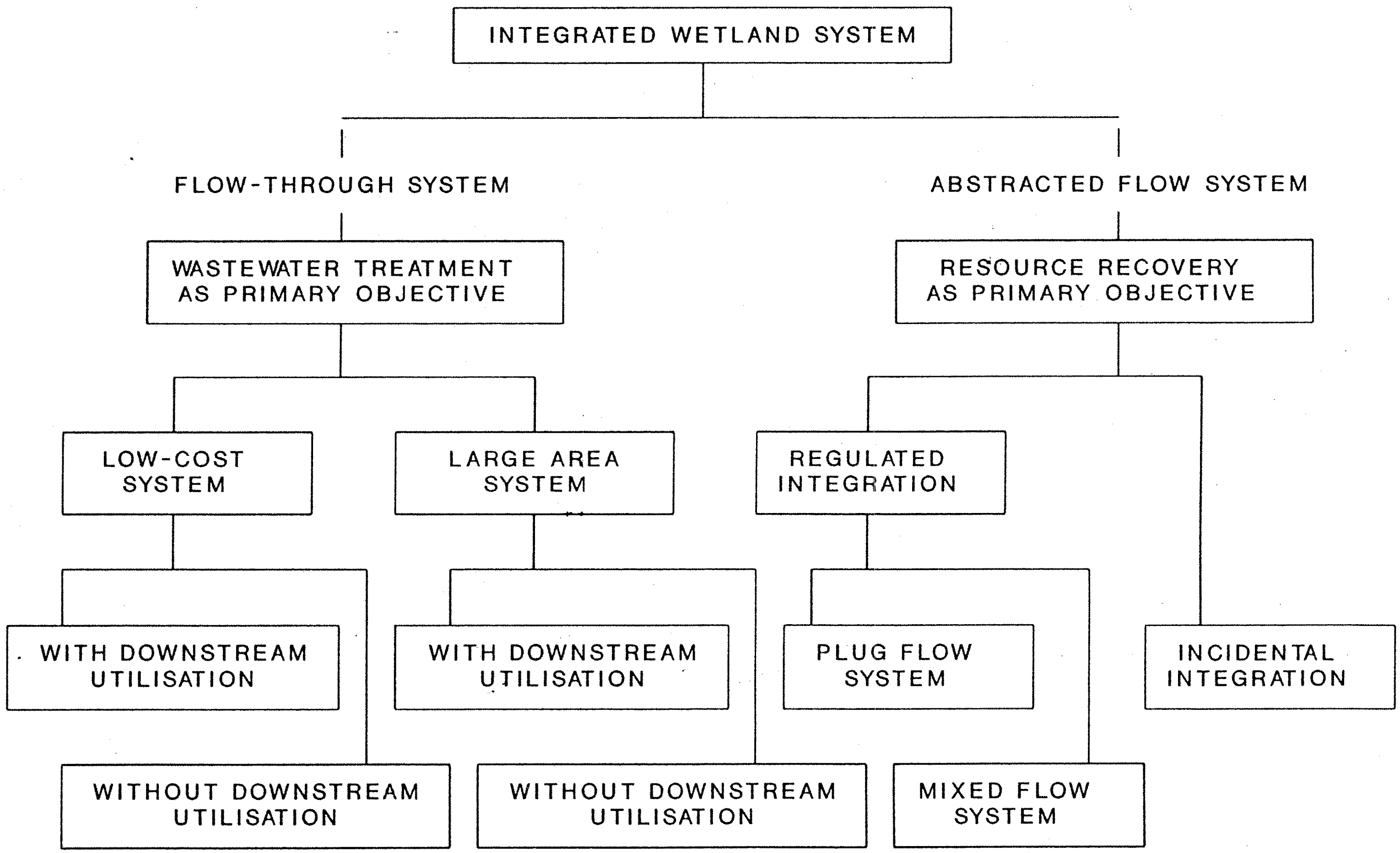


Figure - 1

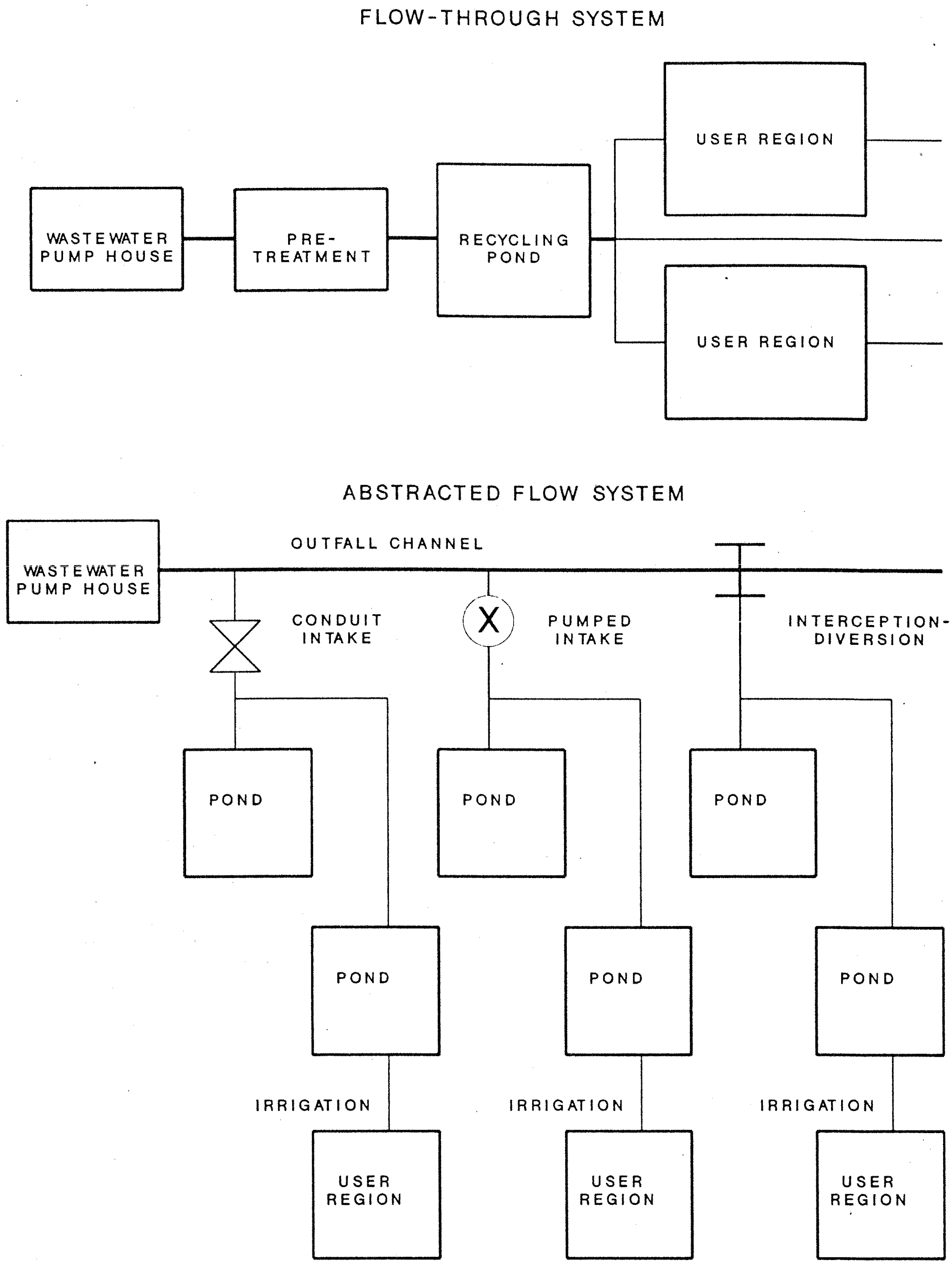

FLOW-THROUGH SYSTEM
WASTEWATER PUMP HOUSE
PRE-TREATMENT
RECYCLING POND
USER REGION
USER REGION
ABSTRACTED FLOW SYSTEM
WASTEWATER PUMP HOUSE
OUTFALL CHANNEL
CONDUIT INTAKE
PUMPED INTAKE
INTERCEPTION-DIVERSION
POND
POND
POND
POND
POND
POND
IRRIGATION
IRRIGATION
IRRIGATION
USER REGION
USER REGION
USER REGION

Figure - 2

the area varies according to the effluent quality requirements. Whereas the 'large area system' emphasizes the need for aquaculture and requires three to four times the area needed for the former option. For any 'flow-through system' the calculations for 'large area system' will be same as that for 'minimum area system' and no additional calculation will be required for the former.

A typical interception-diversion structure on wastewater outfall channels.

1.3 BASIC STEPS FOR IMPLEMENTING IWS PROJECTS

Basic steps for implementing IWS projects are shown in the following flow diagram (figure - 3):

BASIC STEPS FOR IMPLEMENTING IWS PROJECTS

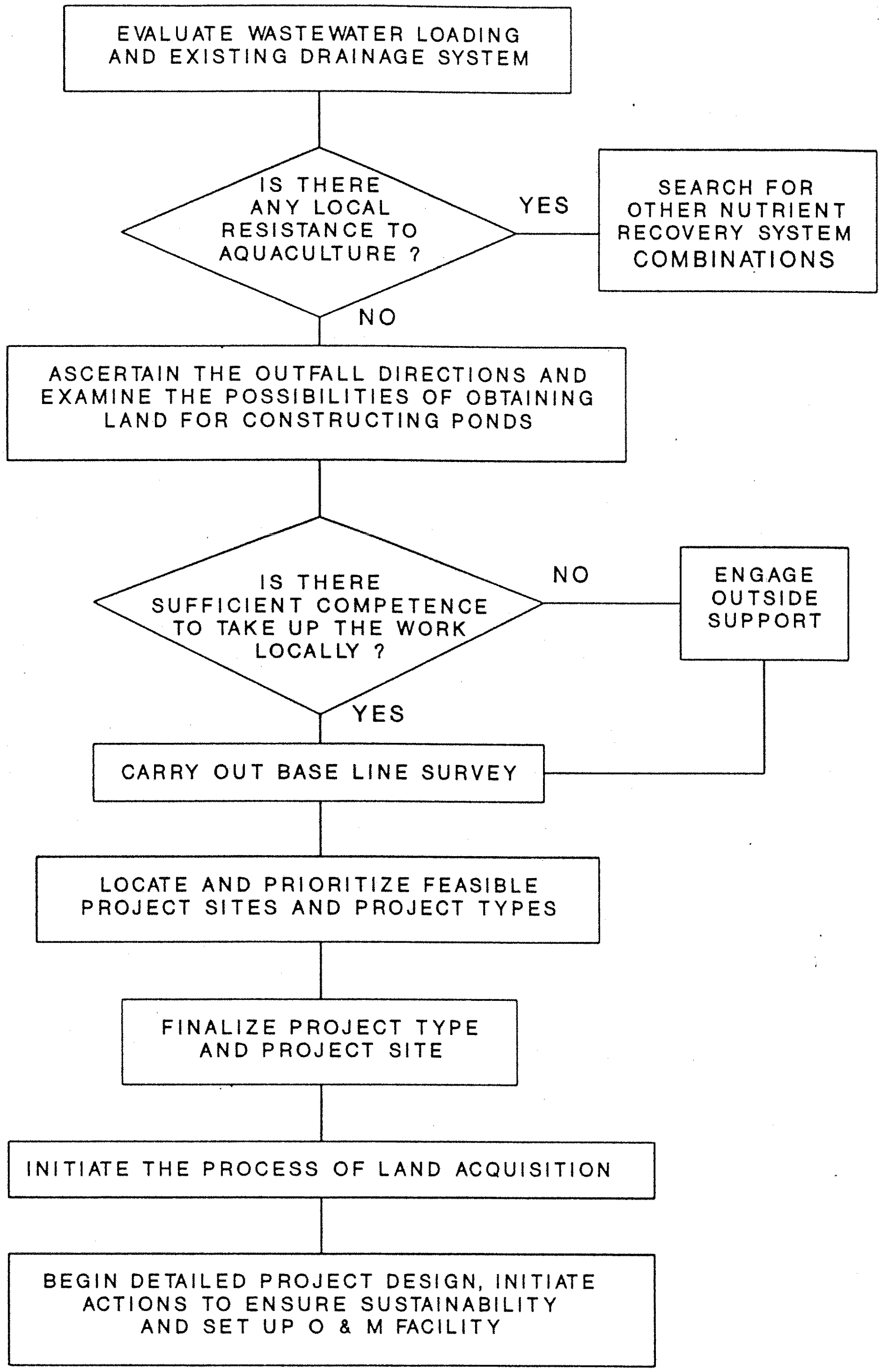


Figure - 3

A short description of the basic steps for implementing IWS projects described in the flow diagram may be useful to understand them better.

1. Evaluating wastewater loading is the first step for taking any practical initiative to implement IWS projects. Most of the subsequent steps depend on the volume of liquid which the system is expected to handle. It is also essential to identify the existing drainage system through which the effluent from the project will finally flow down.

2. Local resistance to aquaculture will have to be identified before starting any project planning. Although in most parts of the developing countries people consume fish, there are places where the local people do not eat fish. However tendency to grow fish is also found where fish is not locally consumed because fish growers are able to earn reasonable profit by selling them to other markets. In case there is any taboo against growing fish it will be necessary to search for other nutrient recovery options.

3. Ascertaining outfall direction is important to narrow down the area in which appropriate project site will have to be found out. After a number of possible project sites are identified it is necessary to carry out a'base line survey'. Base line survey will include :

* hydraulic survey
* soil survey
* topographical survey
* land use survey

In most cases it may be possible to carry out the base line survey drawing upon the locally available competence. However, it may be necessary to engage outside support in some cases.

4. The task of prioritising the available options is a difficult challenge and needs considerable application of pragmatism, ecological sense and engineering foresight. It is advisable to bring together the best available people to complete the task of finalising the project site and type.

5. Land acquisition formalities are different for different countries and even there are differences from place to place within the same country. Nevertheless completion of acquisition formalities in a legally valid manner is one of the fundamental pre-requisites for IWS project implementation.

6. Detailed project design can be taken up simultaneously and after its completion project construction begins followed by system start up. A commissioned project can successfully perform only when there is an efficient operation and maintenance support. Finally, steps will have to be taken to ensure the sustainability of the project by safeguarding against engineering as well as economic risks.

1.4 ADVANTAGES OF AN INTEGRATED WETLAND SYSTEM PROJECT

In many cities of the developing countries the wetlands or natural depressions act as receiving waterbodies where the city's wastewater accumulates. These waterlogged areas, more often than not, become sources of health risk for humans. However, planned use of these receptacles, which is seen in the eastern wetlands of Calcutta, can entirely change the scenario in favour of a sustainable technology for wastewater treatment and resource recovery. The following are the advantages of such a wetland system :

1) **Reduced consumption of conventional energy**. IWS is basically a solar reactor and completes most of its biochemical reaction with the help of solar energy. Reduction of BOD (biochemical oxygen demand) takes place because of a unique phenomenon of algae-bacteria symbiosis where energy is drawn from algal photosynthesis.

2) **IWS is a flexible system.** Any sewage treatment facility is designed on the basis of a projected population (20 years projection will be usual).It is natural that the design flow cannot be reached at the beginning. The flow will steadily rise to the design value in course of the projected life-span. It has been found that conventional treatment plants suffer from non-availability of sewage and in many cases continuous recirculation of effluent wastewater becomes unavoidable rendering the facility much more energy expensive. IWS on the other hand, is a flexible system and can work with almost no-flow condition to full-flow condition with uniform proficiency and minor adjustments.

3) **More efficient removal of coliforms**. Conventional mechanical sewage treatment plants (trickling filters or activated sludge plants) are largely inefficient in removing coliform bacteria. Coliform is the indicator species for faecal bacteria which are likely to be pathogens.Recommending conventional sewage treatment plants without tertiary treatment will be a big compromise with the desirability of public health standards and perhaps highly ineffective investment of scarce capital. IWS on the other hand, can ensure reasonable reduction of coliform bacteria primarily because of the detention time it allows to the incoming wastewater.

4) **Enhancing food security.** IWS compulsorily includes pisciculture, agriculture, horticulture and animal husbandry. All these systems have a common and rich nutrient base that is drawn from municipal wastewater. It has been observed that the productivity of these multiple food growing systems

goes a long way to integrate the IWS option with the mainstream development activities unlike the conventional sewage treatment plant which is invariably considered as an externality in the basic social and economic activities of a city and its fringe.

5) **Contributes to rural development.** IWS projects have significant role in rural development. Completion of IWS projects triggers a chain of economic activities by providing enriched irrigation water in addition to the piscicultural units which form a part of the system. In West Bengal there are examples of thoroughly rejuvenated rural economy developed within a short time of the completion and start-up of IWS projects .

6) **Institutionalizes participation of the stakeholders**. Agenda-21 has laid particular emphasis on institutionalizing participation of the stakeholders in environmental improvement projects. For conventional mechanical sewage treatment plants such an opportunity is marginal. On the contrary, for IWS projects, institutionalization of local people's participation at all major levels of planning, construction and particularly maintenance is a basic need for successfully running the system. After completion of the projects, it has been possible to give the local rural authorities the responsibility of the day-to-day maintenance of the system.

7. **Longer life-span of the treatment facility.** The conventional sewage treatment plants are prone to damage and frequent breakdowns. A huge financial liability accrues to the parent municipal authority to properly maintain such treatment plants. Unless continuous financial assistance can be arranged from outside no municipal body in the low income countries can afford to run conventional mechanical sewage treatment plants. IWS, on the other hand, is a revenue earner. For the purpose of fund allotment, municipal responsibility for all practical purposes, ends at the pumping station from where the wastewater flows to the IWS system by gravity. IWS is a wealth generating ecosystem and proper management can not only make it self-reliant but adequately profitable. Furthermore, being a non-structural option, the problem of damage and breakdown does hardly arise and the system can continue to work for any length of time without any major system disorder.

8. **Minimum construction time**. Time of completion of any conventional mechanical sewage treatment plant will be around five years if not more.For economies with inflationary pressure the time taken for construction escalates the price considerably. IWS projects can be completed within 18 months and the impact of inflation on the total project cost is noticeably lower than that for the conventional projects.

1.5 INTENDED USERS

The present manual is likely to be useful to a number of groups.

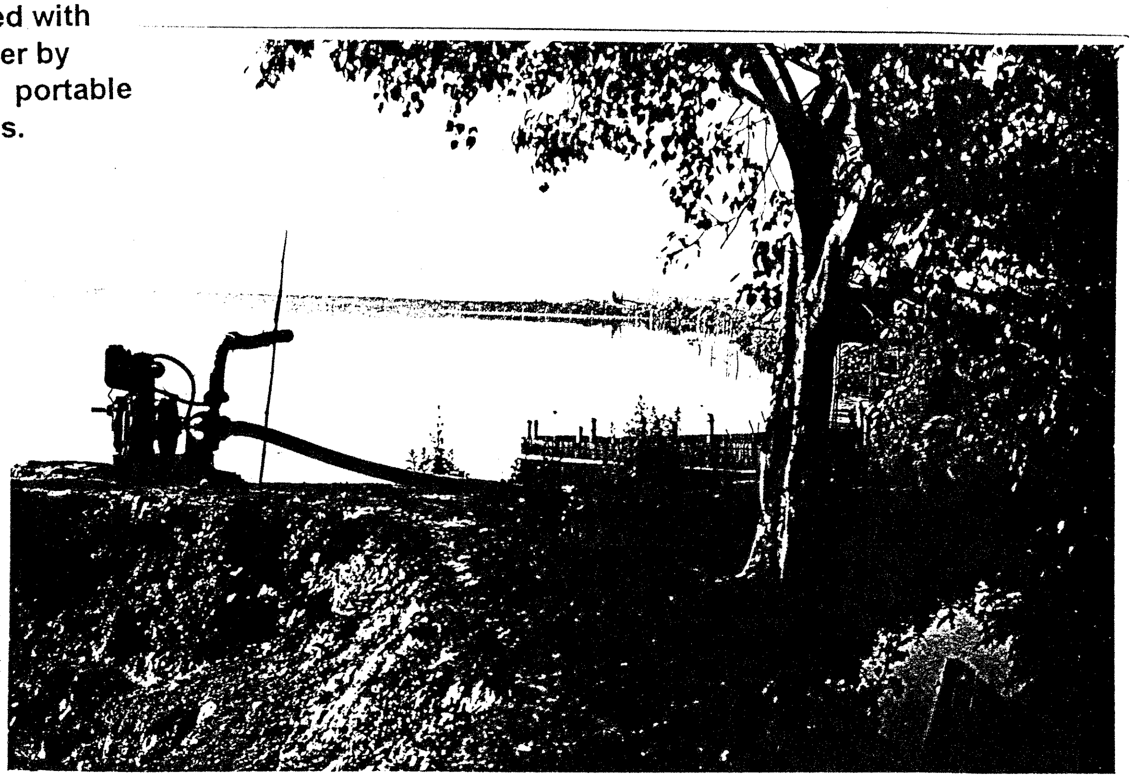
A. **Development related groups dealing with**

1. municipal works
2. urban development
3. river sanitation / urban sanitation
4. rural development
5. maintenance of open space and development of recreational facilities
6. water resource management
7. food security

B. **Environment related groups dealing with**

9. wetland wise use
10. non-conventional energy and resources
11. nature conservation
12. sustainable development
13. stakeholders' participation and research
14. symbiotic ecosystem study
15. fundamental education and awareness

Fish ponds are being filled with wastewater by means of portable pump sets.



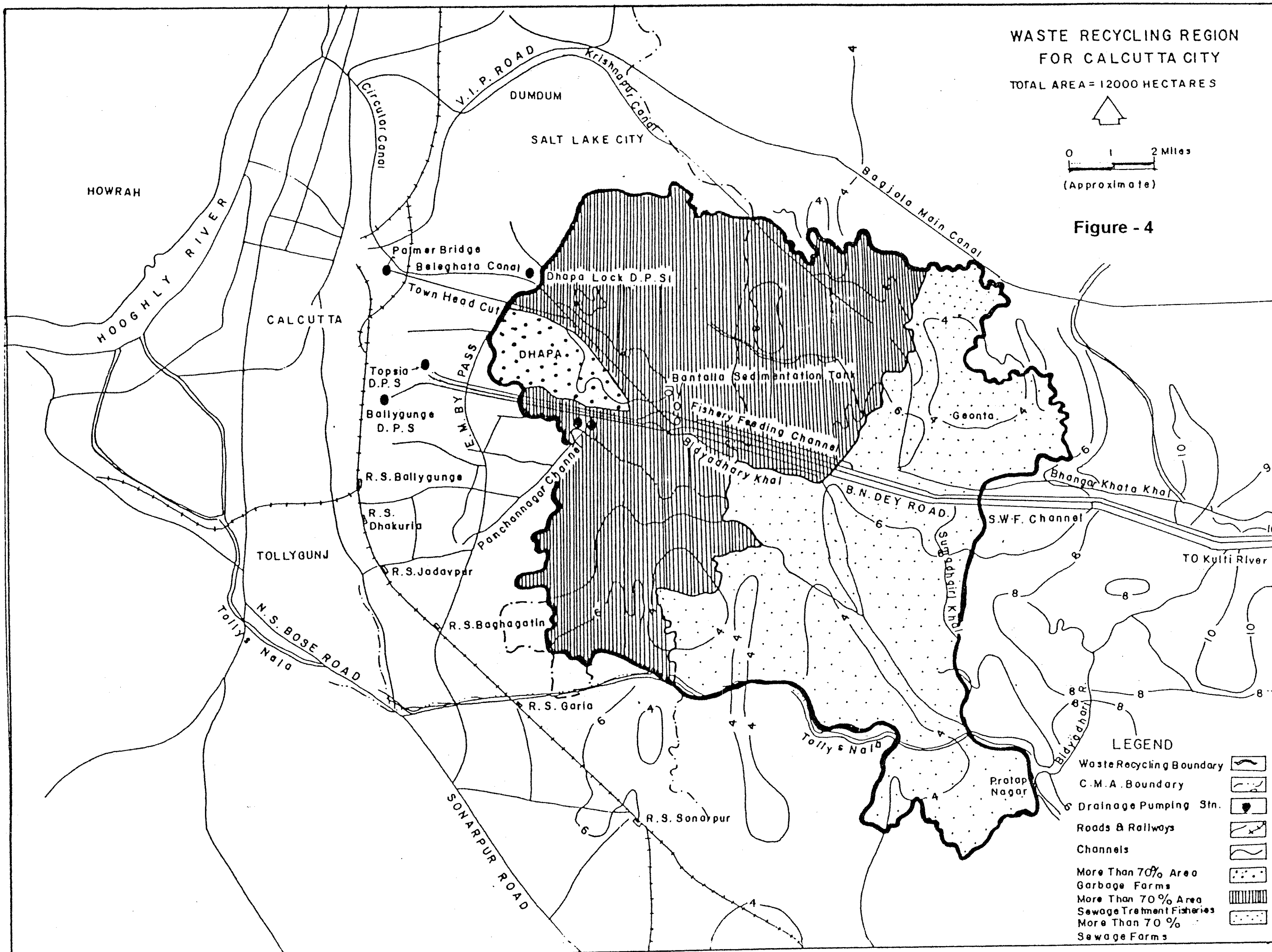
1.6 STATE-OF-THE-ART REVIEW

The concept of integrated wetland system for wastewater treatment and resource recovery is rooted in the traditional practice of using Calcutta sewage in the fisheries and agriculture. Although the knowledge is transferred over the generations through oral tradition only, it is in these wetlands that the state-of-the -art is best exemplified. Scientific studies for understanding the system and deciphering the oral tradition have resulted in the development of engineering design for wastewater treatment and resource recovery system as a mainstream option in urban sanitation. The state-of-the-art review for the proposed IWS will rely mostly upon the lessons learnt from the Calcutta Wetland Practice. For the purpose of the present manual the review is restricted to a brief description of the system, scientific studies undertaken, the working determinants and the development of technology based on it.

In 1980, consequent upon a research initiated by the Government of West Bengal, an assessment of this wetland area and its reuse practices was undertaken. By 1983, the first scientific document on this wetland ecosystem was published which enabled the rest of the world to know about the ecological significance of this outstanding wetland area. In 1985, the map of "Waste Recycling Region " which forms the basis of all planning and development activities on this area, was prepared (figure - 4).

In the same year, the State Government put forward a proposal to introduce the resource efficient stabilisation tank system for treatment and reuse of the city sewage. This was accepted by the Ganga Project Directorate as an alternative to conventional energy expensive and capital intensive mechanical treatment plants. The Government of West Bengal firmly promoted this low-cost option and took up a number of such projects under the Ganga Action Plan in place of conventional mechanical treatment plants.

From the traditional practices of integrated wetland system of Calcutta the technique of using shallow wastewater ponds for recycling urban discharge has been more clearly learnt (figure - 5) and a wider spectrum of design options for transforming city-side wetlands into resource recovery ecosystems is now visible (figure - 6). The table - 1 shows the working determinants in wastewater fish ponds of Calcutta wetlands.



WASTE RECYCLING REGION FOR CALCUTTA CITY

Figure - 4

SUCCESSIVE UTILISATION OF WASTEWATER IN CALCUTTA WETLANDS

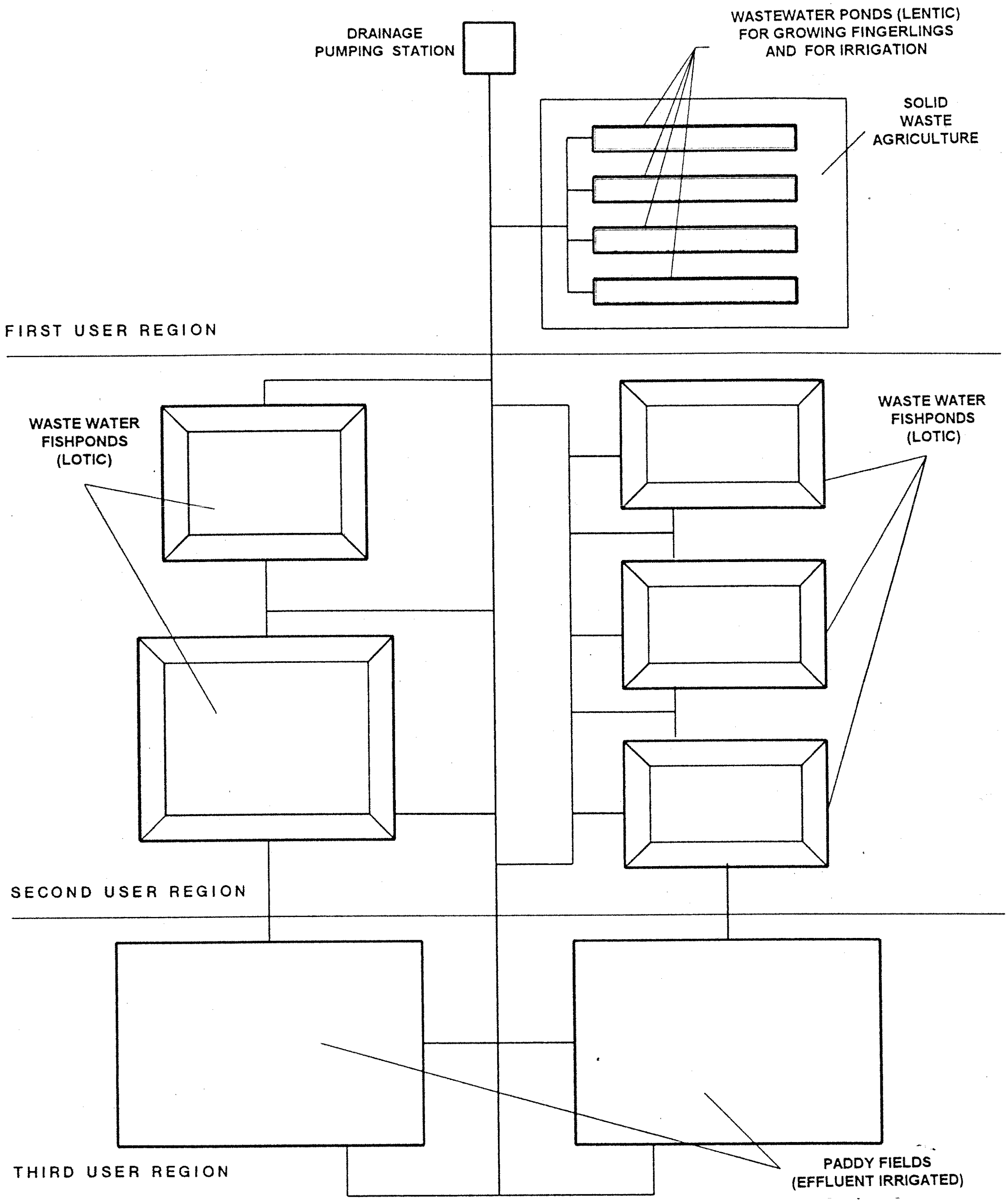
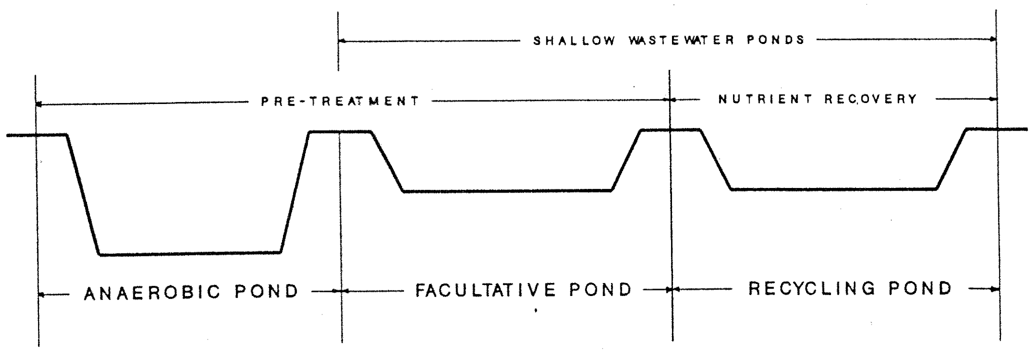


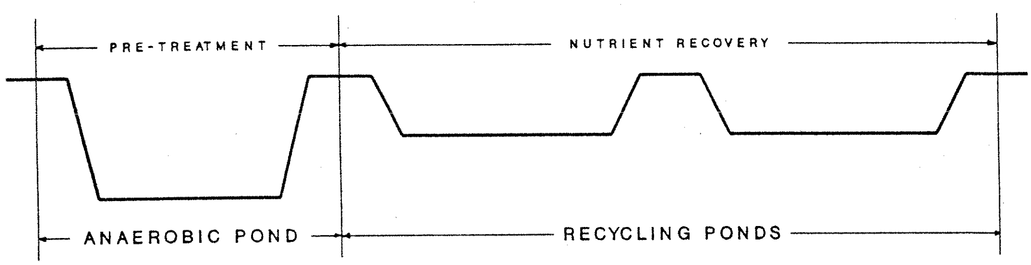
Figure - 5

UTILISATION OF SHALLOW WASTEWATER PONDS

UNDER CONTINUOUS FLOW CONDITION



FULL DESIGN LOAD CONDITION



HALF LOAD CONDITION

UNDER REGULATED FLOW CONDITION

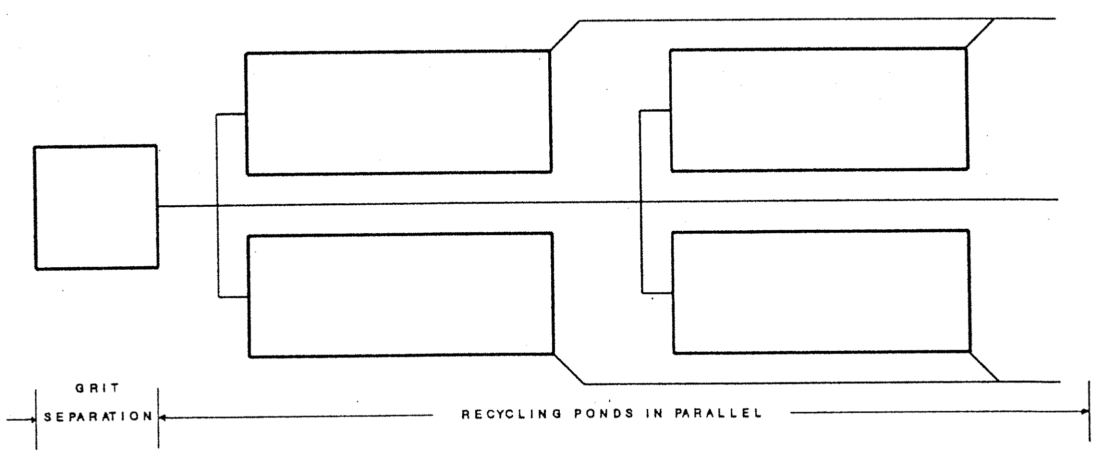


Figure - 6

Table 1: Working Determinants

BOUNDARY CONDITIONS	MAJOR DETERMINANTS
1. Area	Land cost, land use, future plans, awareness about wetland functions
2. Hydraulic Regime	Land formation, groundwater, water retention
3. Micro-climate	location (latitude,longitude), special conditions

OPERATIONAL VARIABLES	MAJOR DETERMINANTS
1. Flow	Urban population, water supply, sewage network, depth of pond
2. Water Quality	Detention time, liming, number of ponds, diversion, diffusion, bed preparation
3.Fish Recruitment and Harvesting	Choice of species, size of recruitment and harvesting, stocking density, harvesting schedule

INSTITUTIONAL FACTORS	MAJOR DETERMINANTS
1. Financial	Land use policy, project viability, hidden investment
2. Co-ordination	National and State plan, nodal initiative, people's awareness
3. Skill, Workers' Welfare & Terms of Labour	Management policy, labour laws, trade unionism
4. Entrepreneurial Risk	Land acquisition plans,chances of wetland reclamation, law and order
5. Training, Information and Awareness	Policy support, scientific and technical programme, NGO activities, missions

2. MAJOR FEATURES OF INTEGRATED WETLAND SYSTEM PROJECTS

2.1 VARIOUS COMPONENTS OF IWS PROJECTS

The major components of the IWS project will include :

* **wastewater collection** from cities through a sewerage system up to the IWS project site (see chapter - 3 for details).

* **pumping** of wastewater to lift it from below the ground and reach it up to the IWS project site occasionally through a force main (see chapter - 4 for details)

* **pre-treatment** of wastewater to ensure safe aquaculture in recycling ponds. This can either be only a strainer or a combination of grit removal system and an anaerobic pond for rapid reduction of BOD in wastewater (see figure -7).

* **primary recycling ponds** or recycling ponds are mixed flow reactors where the functions of nutrient removal and treatment of wastewater take place simultaneously. Secondary recycling ponds are the waterbodies within any user region which recycle effluent from primary recycling ponds and are used for growing fish or other commercial aquatic crops..

* **effluent irrigation in user regions takes place** on the downstream side of the outfall channel can be used for generating crops and planting trees. Fish can be cultured in ponds (which in effect are secondary recycling ponds) using the effluent. Linking user regions with the effluent channels will enhance the food security amongst the beneficiary communities and ensure larger participation of the stakeholders in IWS projects.

It is seen that there is a wide variety of uses and varying hydrologic conditions through which an appropriate set of options and components are to be determined. Unlike the definitive approach of conventional wastewater treatment plants where details of design and performance are more clearly available, IWS projects do not have enough time-tested information to produce specific formulation of that nature. Nevertheless, information available from existing systems, both traditional and formal, can produce workable guidelines and inspire for choosing the IWS option and selecting the appropriate component options.

COMPONENTS OF IWS PROJECT

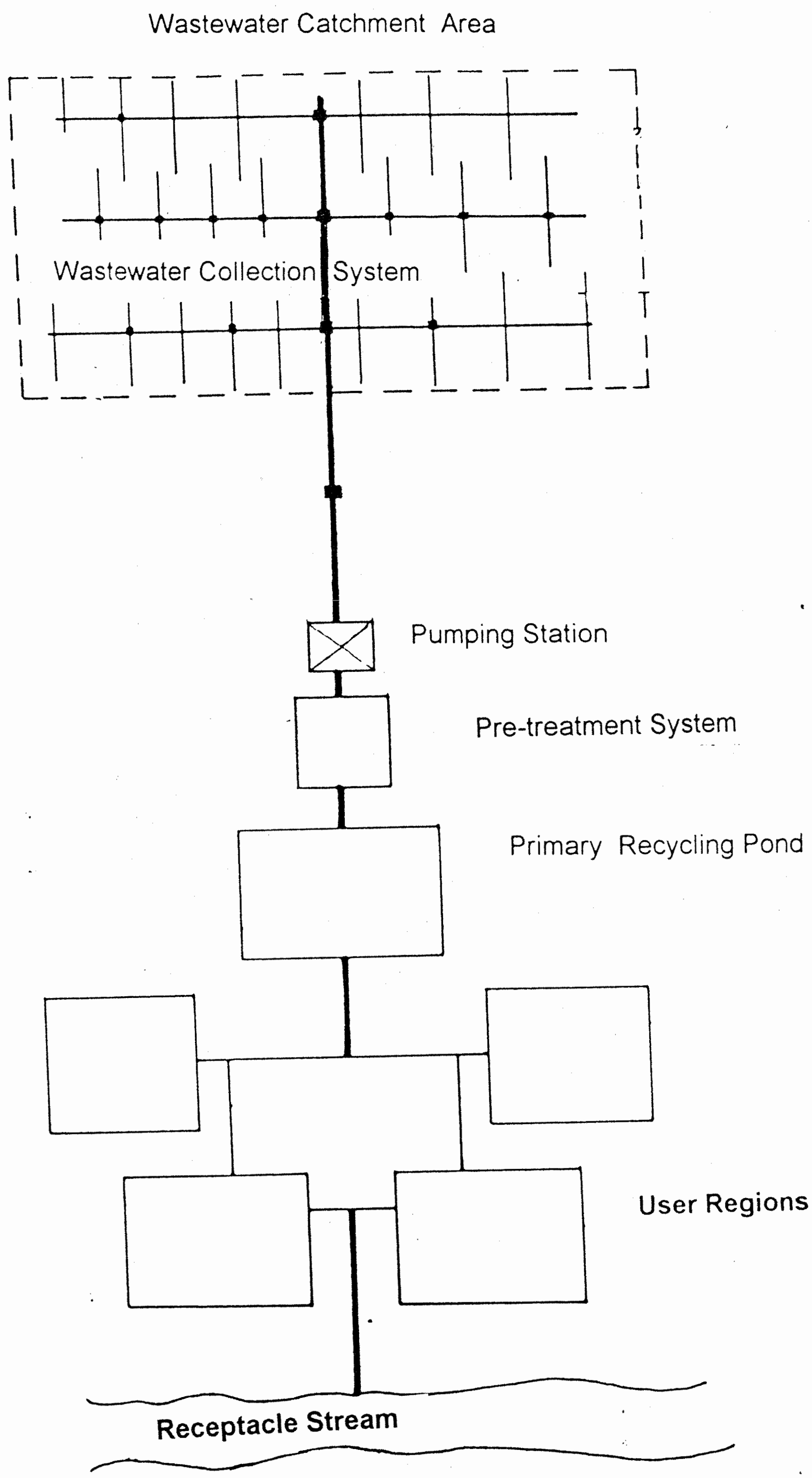


Figure - 7

2.2 MORE ON USER REGIONS

It is understood that the effluent from the recycling pond is an excellent source of irrigation water for raising additional crops in those areas that can avail of its supply (user regions).

No single crop requires irrigation at a uniform rate throughout its growing period. The strategy for optimum utilization of effluent is to find out such crop combinations so that aggregate irrigation demand is equal to the daily/periodic discharge from the recycling ponds. If the profile of irrigation requirement for each crop is plotted for a length of time, it will resemble a saw tooth. Appropriate choice of crops can create a uniform irrigation demand which is equal to the effluent disposal from the recycling ponds. (Figure 8) is a highly simplified version of the effluent utilization strategy discussed above.

EFFLUENT UTILISATION IN AGRICULTURE

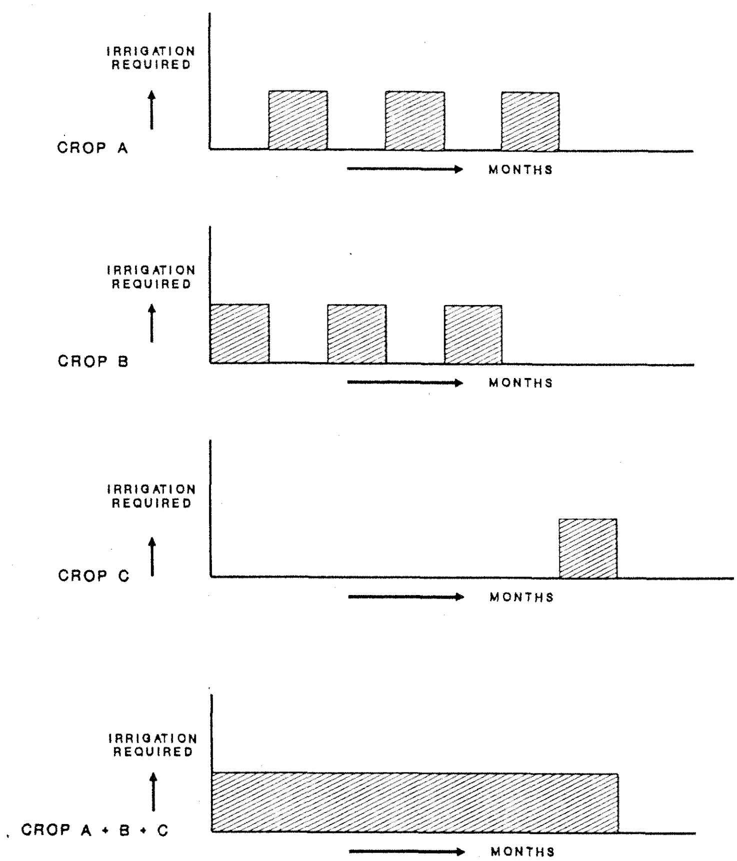


Figure - 8

2.3 ECOSYSTEM AND ECOLOGICAL CRITERIA

Public health engineers found out that when wastewater was introduced in shallow ponds and was detained there for about seven to ten days, the quality of water improved and the effluent quality was as good as that from a secondary treatment plant. The oxygen demand of organic matter present in the wastewater was met by algal photosynthesis facilitated by insolation.

Fish farmers in the wetlands of east Calcutta found out that if wastewater flowing from the city was introduced in shallow ponds and was detained there for several days the resultant water became rich in algae and plankton. The food and oxygen demand of the fish was met by the algal biomass produced in the pond with the help of insolation.

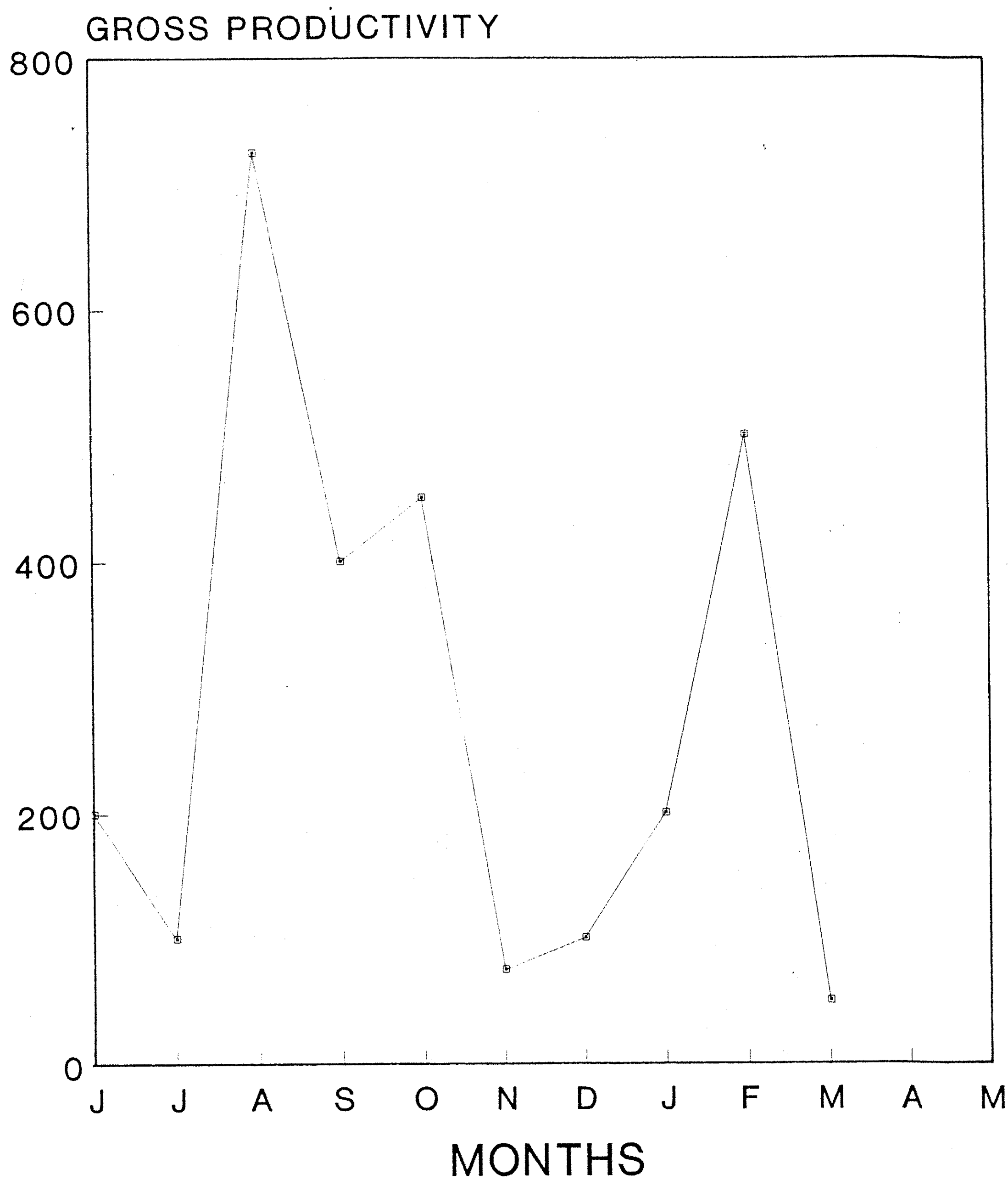
The recycling pond is only a new definition for the same shallow pond which is known to public health engineers as stabilisation pond or more precisely, maturation pond and to the fish farmers as 'bheri'. The present understanding of this shallow aquatic ecosystem recognizes nitrogen, phosphorous and calcium available from wastewater as vital nutrients for pisciculture. On the other hand relatively high level of CO_2, pathogenic bacteria and lack of dissolved oxygen at night are to the detriment of growing fish. The challenge for a proper recycling pond to function is to manipulate the ecosystem in way that growth of fish is not threatened. This ecological management depends on the understanding of few basic processes that operate in such shallow aquatic ecosystems. These are trapping of solar energy and its flow through various trophic levels, the algae-bacteria symbiosis and oxygen transaction. A discussion about these natural biological phenomena follows :

a) functioning of recycling pond as a solar reactor

Shallow wastewater pond acts primarily as a solar reactor where solar energy is trapped as chemical energy in the aquatic micro and macro flora by the process of photosynthesis. The total energy incorporated in the living plant tissue is termed as the gross primary production whereas the net primary production is obtained by deducting the loss of energy due to plant respiration from the gross value. This chemical energy in form of sugar circulates through different organisms and trophic levels. In example of seasonal variation of gross productivity is shown in (figure - 9).

In the shallow wastewater ponds the primary producers are the phytoplanktons and algae. Grazing on them are the primary consumers - the herbivores (zooplanktons for example). Herbivores are fed upon by secondary consumers - the zooplankton feeders like Catla catla. This is how the grazing food chain is formed in the aquatic ecosystem of the present kind. At every trophic level transformation of energy incurs a loss of about 90%. In other words, fish feeding upon lower trophic levels will have more efficient growth (Grass Carps for example).

SEASONAL VARIATION OF GROSS PRODUTIVITY



Source : Ghosh, A; Rao, O.L.H.; and Banerjee, S.C., 1974. Studies on the hydrological conditions of a sewage-fed pond with a note on their role in fish culture.

Figure - 9

The degraded organic waste and the debris from grazing food chain settle at the pond bottom and are known as 'detritus'. The energy contained in the detritus is used by detritivorous fishes like Cirrihinus mrigala. This food chain is termed as detritus food chain and is highly significant in pond ecosystem management. Although the amount of energy flow through detritus food chain is lower than that in the grazing food chain, this is well compensated by a greater amount of detritus material present at the pond bottom which gets converted into fish food.

The organic matters present at the pond bottom are decomposed by the micro-organisms of the detritus food chain which break down the dead tissues into simpler forms and release nutrients like nitrogen and phosphorous. This produces a productive substrate for the fish to grow. This is also a good reason why fish should be introduced to manage shallow wastewater pond ecosystems.

b) algae-bacteria symbiosis

The algae in the shallow wastewater pond ecosystem has two major utilities : it is the food for some fish species and is a source of oxygen in the aquatic habitat. Carbon dioxide produced as a respiratory end product is the carbon source for algal biomass (figure - 10) :

ALGAE - BACTERIA SYMBIOSIS

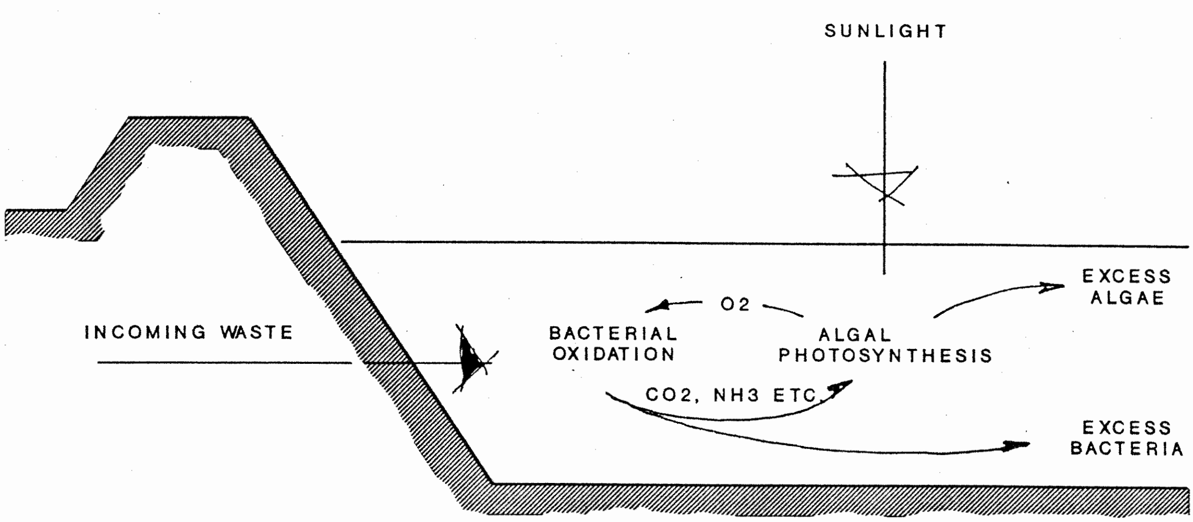


Figure - 10

c) oxygen transaction

Concentration of oxygen in water is less than that in atmosphere and is produced by photosynthesis in micro and macro aquatic flora and also from aquatic CO_2. Aquatic ecosystem rich in plankton and algal population also contains supersaturated level of dissolved oxygen. However this oxygen concentration is dependant upon solar radiation and in the absence of sunlight this value drops down. This is why a wide variation of oxygen concentration from about 0.5 mg/l to about 20 mg/l is observed in such waterbodies.

The dissolved oxygen in shallow aquatic ecosystems is utilized in a number of ways which include :

i) respiration by the aquatic animals
ii) respiration by the aquatic plants
iii) algal chemosynthesis
iv) bacterial respiration
v) decomposition of organic matters
vi) oxygen consumed by mud

The oxygen requirement of fish is determined by the temperature and pH of the water, exposure time, size of the species and its physiological adaption. A 10°C rise in water temperature approximately doubles the respiration rate of the aquatic animals.

Actual measurement of consumption is difficult. For management purposes it is enough to measure the early morning dissolved oxygen level which should not preferably drop below a threshold level of about 1.0 - 2.0 mg/l.

2.4 IWS PROJECTS AS A COMPONENT OF URBAN PLANNING

Urban planners and engineers, in view of their new obligation towards environmental protection and sustainable development, will give particular attention towards a number of natural resource systems of which wetlands are amongst the foremost. Wetlands which are used for wastewater treatment and recycling basically work as unique urban facility and demonstrate a different kind of wetland wise use model and are particularly relevant for the poorer cities of the world. It is time that ecologically gainful projects like this got included into the mainstream development plans of countries or regions.

STEPS FOR INTEGRATING IWS PROJECTS
IN THE URBAN PLANNING PROCESS

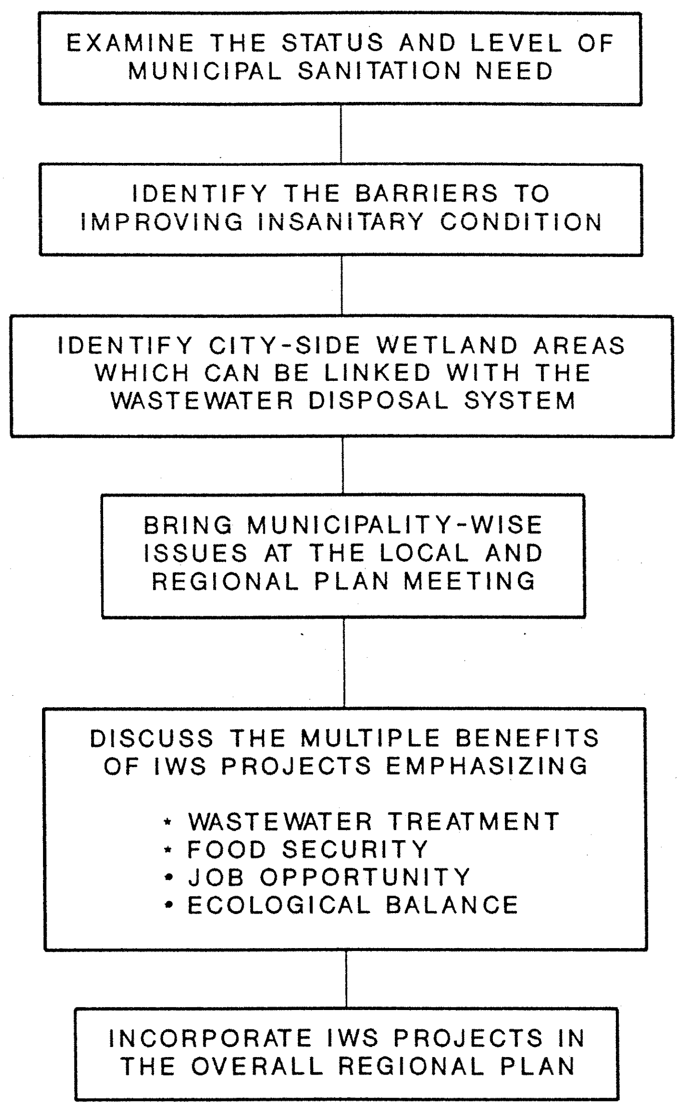


Figure - 11

3. HYDRAULIC LOADING AND SITE SELECTION

3.1 ESTIMATING WASTEWATER LOADING

The quantity of waste to be treated is an important criterion for designing IWS system. For estimating the quantity of wastewater it is necessary to consider :

* per capita water consumption
* existing population
* future growth of population
* industrial waste discharge
* infiltration into the sewers.

The total amount of water supply should contribute to the total flow in a sanitary sewer except for a small portion which is lost through evaporation, seepage, leakage, etc. The rate of water consumption per capita per day for domestic and non-domestic uses can be assumed to be as follows :-

i) For communities with a population upto 20,000 :
water supply through standpost : 40 lpcd (min)
water supply through house service connection : 70 to 100 lpcd
ii) For communities with a population between 20,000 and 1,00,000: :100 to 150 litres
iii) For communities with population above 1,00,000 :150 to 200 litres

In the Indian Code of Basic Requirements of Water Supply, Drainage and Sanitation a minimum of 135 lpcd has been recommended for all residences provided with full flushing system for excreta disposal.

It is expected that about 80% of the domestic consumption will reach the sewer. The water requirements for various establishments should be in addition to the provisions indicated above. The daily per capita requirement in litres in various establishments are expected to be as follows :

i)	Hospital :	
	a) With no. of beds exceeding 100	: 450 per bed
	b) With no. of beds not exceeding 100	: 340 per bed
ii)	Hotels (per bed)	: 180
iii)	Hostels	: 135
iv)	Nurses' and doctors' quarters	: 135
v)	Boarding school/colleges	: 135

vi)	Restaurant	: 70 per seat
vii)	Air ports and sea ports	: 70
viii)	Important railway station	: 70
ix)	Terminal stations	: 45
x)	Non-important stations	: 45
xi)	Day school/colleges	: 45
xii)	Offices	: 45
xiii)	Factories	: 45
xiv)	Cinema house	: 15

It is also necessary to consider the demand for water in the industries. The industries often draw water from underground sources and discharge their effluent into the sanitary sewers. Industrial water consumption in kilolitres per unit is as follows:

Table 2 : Consumption of Water By Different Industries

Industry	Unit of production	Water consumption
Automobile	Vehicle	40
Distillery	Kilolitre (proof alcohol)	12 - 170
Fertiliser	Tonne	80 200
Leather	100 kg (tanned)	4
Paper	Tonne	200-400
Special Quality Paper	Do	400-1000
Straw Board	Do	75-100
Petroleum Refinery	Do	1.5-2
Steel	Do	200-250
Sugar	Do	1-2
Textile	100 kg	8-14

In order to predict future population trend it is necessary to determine the nature and type of growth of the area under consideration. Several methods may be used for predicting future population based on past records. An assumption commonly used for predicting growth of small towns in India is that the present population is likely to double in about 25 years. Present and future industrial waste flows can be known only by surveying the industries that are discharging wastes into the sewers. Allowance to be given for infiltration in sewers will depend on the conditions affecting it and on the judgement made by the designer on evaluating their effects. Depending on rainfall, material of which the sewers are made, nature of joints and height of water table of the place, a suitable estimate has to be made for daily infiltration. Suggested estimates for ground water infiltration are as follows:

lpd/hectare	Minimum =	5,000	: Maximum =	50,000
lpd/km of sewer/cm dia	"	500	"	5,000
lpd/manhole	"	250	"	500

Generally, in a city, the sewers are designed for a minimum load of 150 litres/capita/day. The nature of the sewage to be treated is reflected mainly by the BOD or Biochemical Oxygen Demand value. Other important factors to be considered are the suspended solids, pH, presence of toxic substances, BOD rate constant 'k' and temperature. Generally, for predominantly domestic sewage the BOD can be assumed to be 45 gms/capita/day. After knowing the population to be served the total BOD load can be estimated.

3.2 SITE SELECTION

Selection of appropriate site is one of the key elements in IWS project design. There are three major actors in this activity.

* Local authorities
* Facilitators
* Engineers

Issues to be considered during selection of project site will include :

1. amount of wastewater loading
2. quality of wastewater discharged
3. location of the terminal pumping station (TPS)
4. location of potential user regions
5. location of the receptacle channel
6. area of the project site, cost of land and tenurial status
7. present land use of the project site
8. land use of the area adjoining the project site
9. the lay of the land and relative relief of the project site
10. whether or not the site is being considered for any other development project.

A checklist of issues to be addressed is given below.

Information Sheet For Project Site Selection

SL NO	ISSUES ADDRESSED	
1.	Amount of wastewater loading	i) Design loading in million litres per day (Mld) ii) Wastewater availability during start up (in Mld) iii) The anticipated rate of increment in wastewater discharge for reaching the design load
2.	Quality of wastewater discharged	Wastewater discharge should be studied for : 1. biochemical oxygen demand 2. chemical oxygen demand 3. fecal coliform MPN 4. pH 5. nitrate as N 6. nitrite as N 7. free ammonia as N 8. phosphate as P 9. total solids
3.	Location of the Terminal Pumping Station (TPS)	The location should be shown on a topographical map. It is also necessary to know whether there are other suitable sites for location of the TPS in which case they have to be indicated on the map.
4.	Location of the receptacle channel	The prospective receptacle channel should be identified on a topographical map with clear indication of a) bed level b) direction of flow c) seasonal features d) conservancy, and e) carrying capacity In case more than one receptacle channel are available each one of them should be identified on the map with the above mentioned information for each.

5.	Present land use of the project site	Present land use survey will include information on: a) housing i) no. of dwelling houses within the project area ii)the relationship with and the degree of dependence of the families residing in the project site b) crops grown and wealth created
6.	Location of the potential user region	All the potential user regions will have to be indicated on a topographical map. Additionally, information on each user region will include those on - i) area of the user region ii) crops grown and their economic value iii) irrigational demand of water iv) prospects of other crops to be grown in future and their water requirement (the evaluation of additional water demand will have to be carried out for the whole year) v) number of beneficiaries likely to be facilitated by the IWS project in the user regions and the extent of additional benefit that is likely to accrue
7.	Land use of the area adjoining the project site	This will have to be shown on a topographical map with following details a) drainage lines b) waterbodies c) vegetation d) built up area f) orchard e) cropland g) wasteland h) other open space

8.	Cost of land and tenurial status	1. The cost of land (this should preferably be obtained from the concerned departments of the Government) including the trend of escalation should be examined. 2. Complete details of the tenurial status showing the area under a) public land b) private land c) forcibly occupied land
9.	Lay of the land and its relative relief	1. A general description of the physical feature of the project area and its surroundings including a basin map will be required. 2. Extent of seasonal flooding is to be studied with careful details like - i) exact flood levels marked on permanent structures ii) highest flood level during the last 30 years (These information are important because major conflicts flare up on the issue of flooding after the completion of the project and the local people tend to overlook the level of flooding prior to the construction of the project) 3. Area of waterbodies within the project site should be identified together with the seasonal shoreline changes and vegetative cover 4. It should be found out whether or not the area is a habitat for any ecologically significant life form
10.	Whether or not the project site is being considered for other development projects	This information is to be collected from the local bodies and impact of such development project on local people and ecosystem will have to be anticipated.

3.3 DECISION MAKING

The process of decision making will be to relate the information available from prospective project sites with the various IWS project types discussed in the previous chapter and to bring out the best available option. (Figure - 12) describes the steps for selecting a suitable project site.

These steps will have to be followed after collecting detailed information about the possible project sites and preparing a comparative statement which should include following variables :

i) cost of land
ii) tenurial status (including nature and degree of encroachment, if any)
iii) number and areas of user regions which can be linked with the central outfall channel.
iv) conservancy of the receptacle channel
v) facilitated and additional wealth created from wastewater fisheries and irrigation.

A typical wetland area which can be a potential project site.

STEPS FOR SELECTING IWS PROJECT SITE

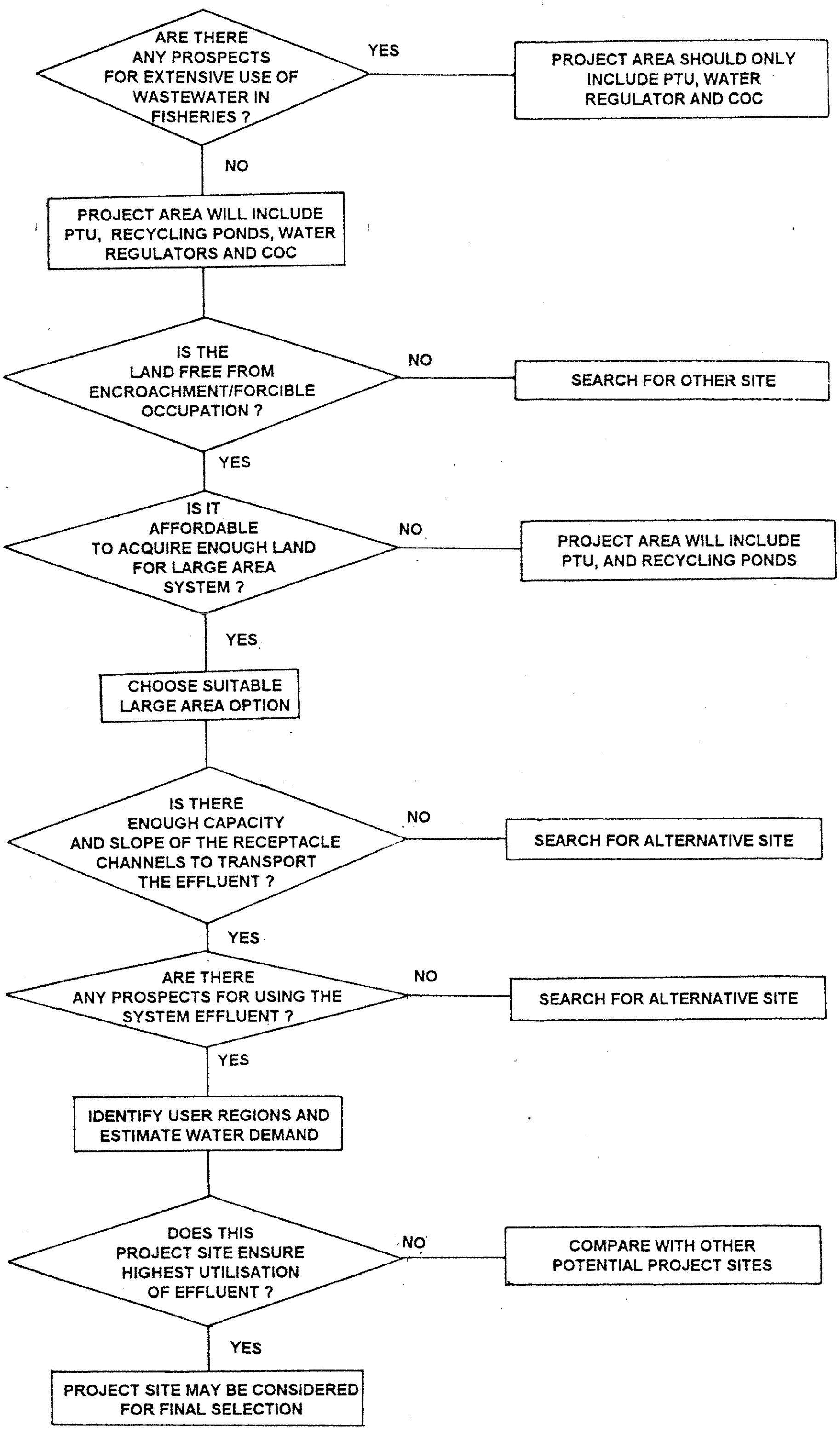


Figure - 12

4. DESIGN OF INTEGRATED WETLAND SYSTEM

4.1 SEQUENCE OF ACTIVITIES

The sequence of activities for designing IWS project is shown in the flow diagram which provide a preliminary understanding of the task. The major steps are as follows :

DESIGN SEQUENCE FOR IWS PROJECTS

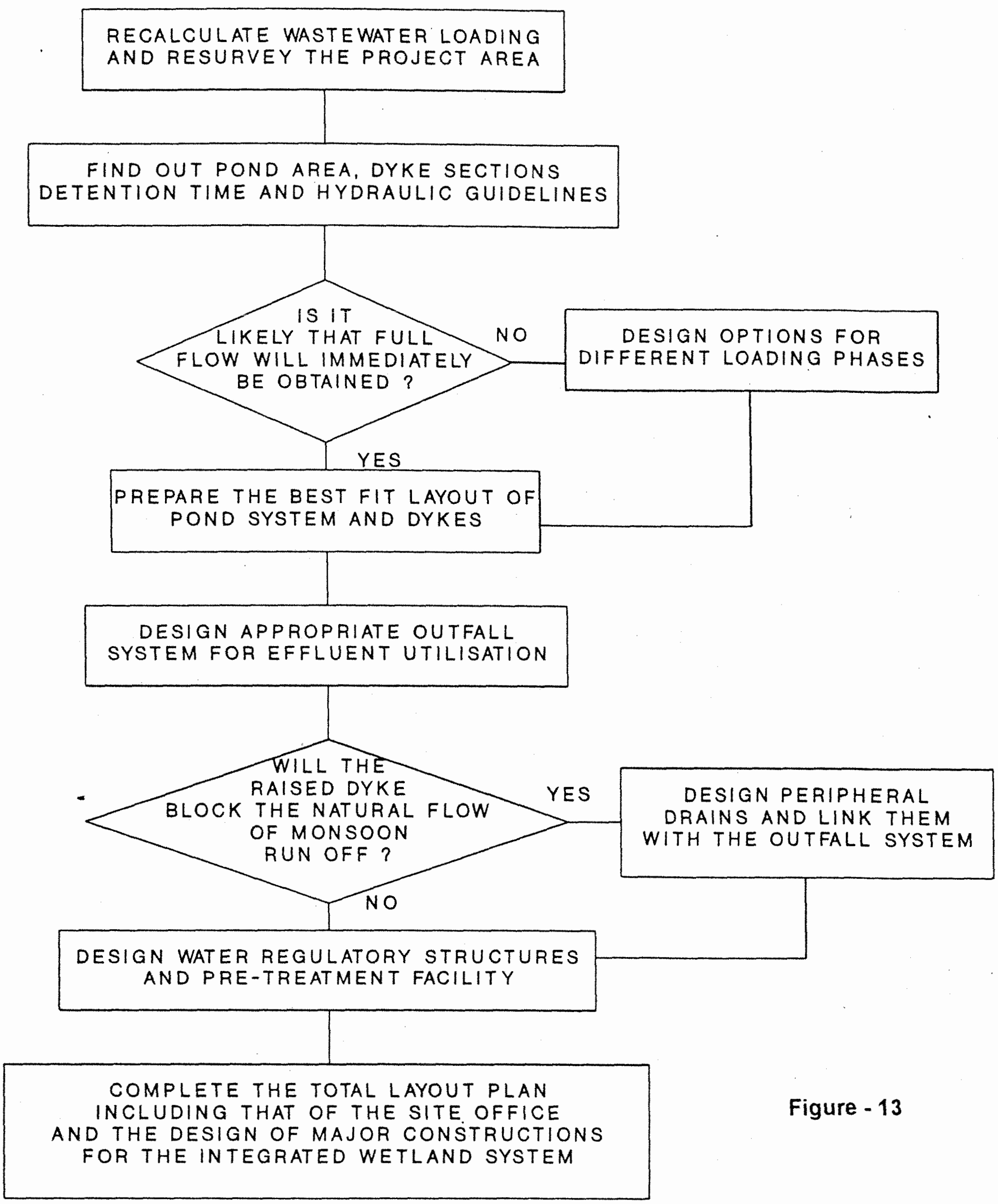


Figure - 13

4.2 DESIGN OF PRE-TREATMENT SYSTEM

A) Grit Screening

Screening of grit materials is an essential step for avoiding damage to pumps and other equipments. Screens are generely installed ahead of the pumping stations and other pre-treatment units. For a relatively small pump house a combined foot valve and strainer may provide sufficient protection for a pump. For larger pumping stations either bar screens and self cleansing medium or fine screens should be installed. Coarse screens or bar screens sieve the weeds, reeds and other floating debris.

The screen channel should be so designed as to prevent the accumulation of grit and other heavy materials. The channel floor should slope towards the screen and should be without pockets which may trap solid materials in them. A channel with a straight conduit like structure perpendicular to the screen facilitates uniform distribution of grit particles throughout the flow and on the rack. For providing adequate screen area for accumulation, it is required that the velocity of approach be limited very nearly to 0.45 metres/second at average flow. The headloss through unobstructed screens mostly depends upon the nature of the open area, blocked area, shape of the screen elements and approach velocity. The accepted practice is to provide a loss of head of 0.15 metres but the maximum loss with clogged hand-cleaned screen should not exceed 0.3 metres.

The quantity of grit present in the sewage in countries like India ranges usually from $0.026\ m^3/1000\ m^3$ to $0.09\ m^3/1000\ m^3$ with peak load of as much as $0.37\ m^3/1000m^3$to $0.74\ m^3/1000\ m^3$ lasting for an hour or two. The quantity of grit removed by bar screens usually varies from about $0.0035\ m^3/1000\ m^3$ to $0.0375\ m^3/1000\ m^3$ of wastewater treated, the average being about $0.015\ m^3/1000\ m^3$.

A coarse screen is also necessary to protect pumps. A coarse bar screen consists of vertical or inclined bars spaced at equal intervals across the channel. It is customary to provide a bar screen with relatively large openings of 75 mm to 150 mm ahead of the pump house for raw sewage. Medium bar screens have clear openings of 20 mm to 50 mm. Bars are usually 10 mm thick on the upstream side and taper slightly to the downstream side. The bars used for the coarse screens are rectangular in cross section of about 10mm x 50mm and are placed with the larger dimension parallel to the flow.

B) Anaerobic Pond

Anaerobic ponds are effective natural biological pre-treatment facilities. In such ponds raw sewage is retained for a short period in contact with the digest solids. Although the amount of dissolved oxygen is normally negligible throughout the

PRE-TREATMENT SYSTEM

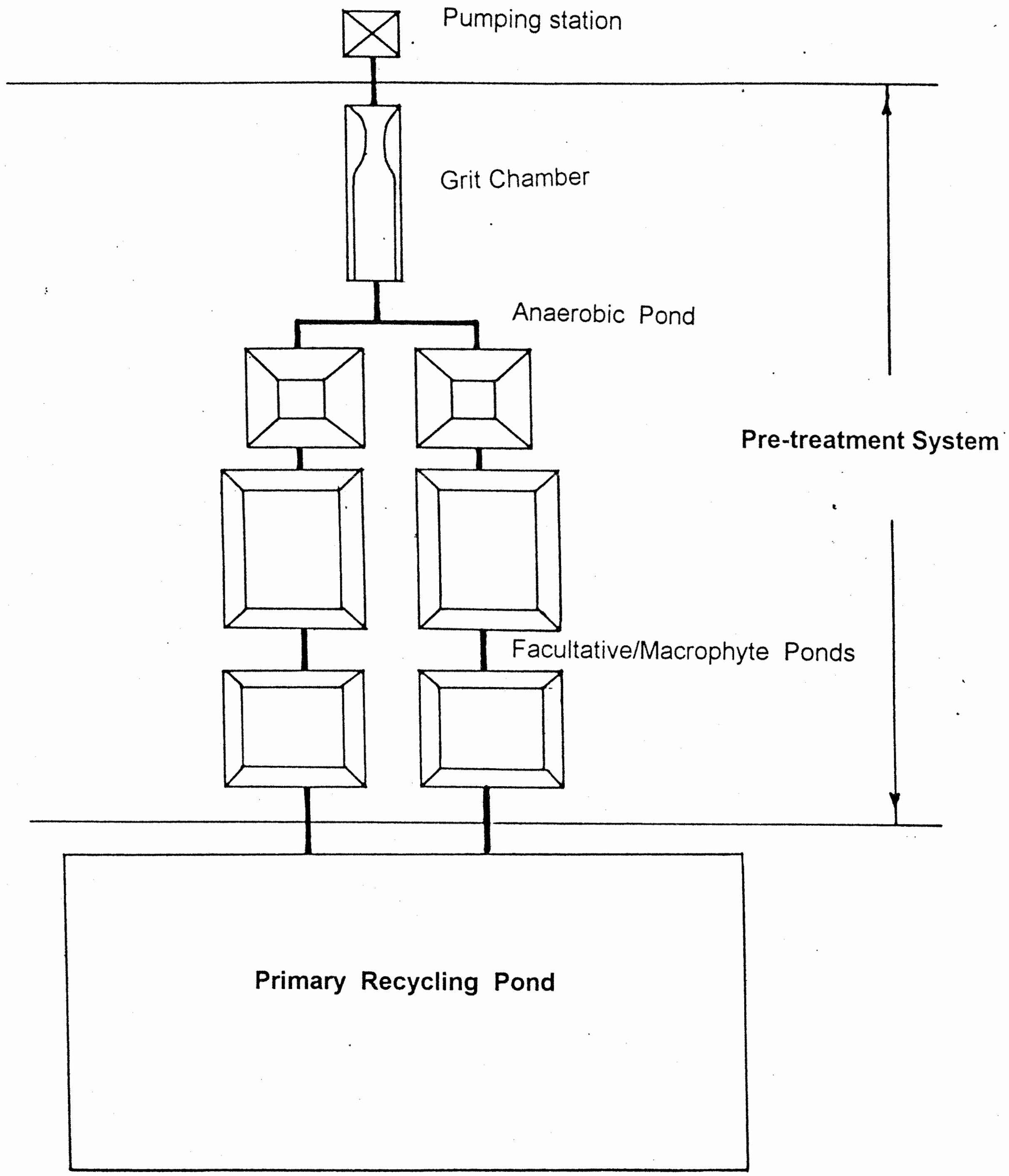


Figure - 14

columns of the anaerobic pond still the reduction of BOD is substantially high. This pond is devoid of molecular oxygen and anaerobic and facultative bacteria obtain their required oxygen from chemical compounds present in the waste. Under these conditions the pond acts like an unheated and unstirred open digester. Anaerobic decomposition degrades organic matter through successive steps to gaseous end-products like methane and carbon dioxide. Anaerobic decomposition of wastewater instabilisation pond is a mixed cultural process consisting of two phases: i) degradation of higher organic matter into volatile organic acids, and ii) fermentation ofthe organic acids into methane and other gases. The former is caused by both facultative and anaerobic bacteria which are in abundance in nature. The latter is brought about by methane bacteria which are strict anerobes. In the anaerobic ponds, it has been observed that upto a detention time of one day the removal efficiency is high and then it drops rapidly with increasing detention time. Detention time of more than two days is not generally recommended.

Table 3 : Relationship Between Detention Time & BOD Removal

Detention Time in Days	Percentage of BOD Satisfied in an Anaerobic Pond
1	50.0%
2	59.0%
3	62.5%
4	66.5%
5	70.0%

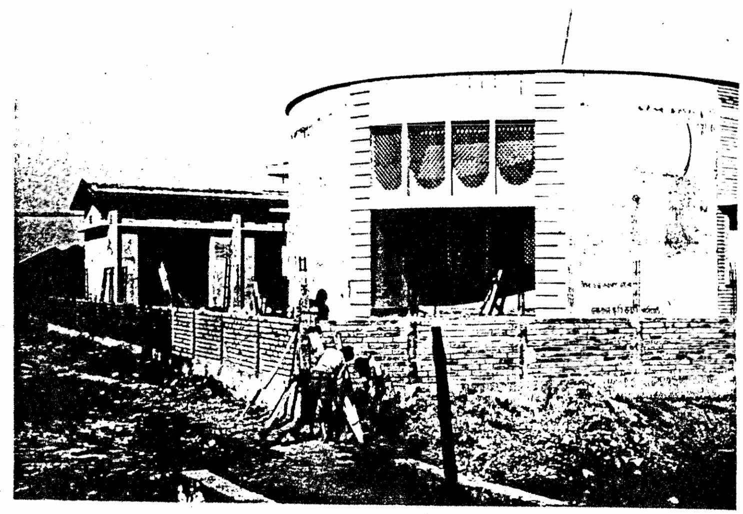
4.3 POND DYKES AND REGULATORY STRUCTURES

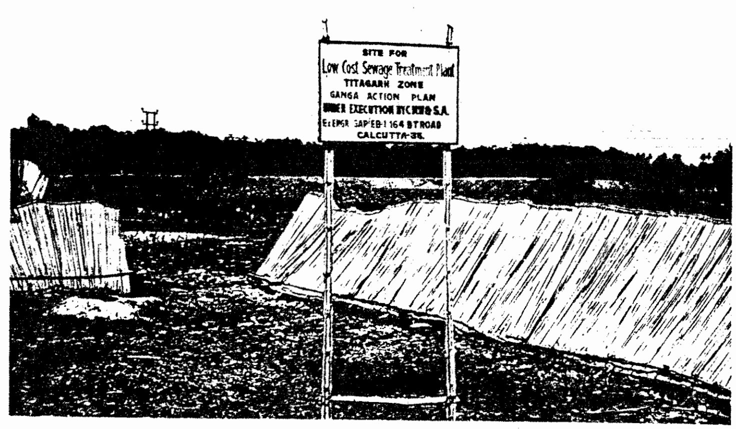
a) Pond Dykes

Dyke elevation must be above the local high flood level.The main factor for designing the side slope is the nature of the soil with which the dyke is constructed. Dykes should be made of impervious materials with provisions for preventing erosion by wave action. After removal of any debris, the topsoil removed from pond bottom may be used as a cover material on the outer slopes of the embankments. Excavated earth can also be used to construct dykes and to balance the cut and fill in earthwork.

Factors other than soil type that should also be considered include seepage inflow into the canal which promotes cave-in. Gentle side slopes are to be recommended where such seepage takes place. Special conditions, e.g., a road running along the dyke or provisions for extended dyke plantations may also require gentler side slopes. Dykes around the ponds should have a top width of at least 1.5 metres. In order to be accessible to hand carts, jeep, moving machines and other maintenance equipments the top width should be 3.0 metres.

Construction of ponds for wastewater treatment and resource recovery under the Ganga Action Plan in Titagarh Municipality, West Bengal, India





The dykes for large ponds should be constructed very carefully. There must be a close supervision on the selection and placement of filling material depending on the soil moisture content and compaction. Materials containing organic matter such as grass must not be used in constructing the core of the dyke or of the embankment. All topsoil must be removed and a suitable foundation prepared before filling materials are placed in position. The impervious material available must be placed at the centre of the embankment. Successive loads of fill must be placed in a manner so as to produce the best practicable distribution of material. Each successive layer of the filling material should have the optimum practicable soil moisture content required for compaction purposes.

Dykes should be constructed in such a manner that excessive seepage through them or between the embankment and the natural ground can be prevented. The slope of the dyke will be determined by nature of the soil and size of the installation. Side slopes generally become more stable once they have been planted with various types of vegetation cover. Steep side slopes save land and earthwork in excavation. However, they are possible only with cohesive and well aggregated soils or where bank protection measures are adopted. Unprotected side slopes should not generally be steeper than 1:2 to avoid serious cave-in. Some general guidelines for design are presented in the following table :-

Table 4 : Limitation on flow velocity and on side slope in drainage system

Soil Type	Maximum Permissible Mean Flow Velocity (m/s)	Maximum Permissible Side Slope
Fine sand	0.15 - 0.30	1:2 to 3
Coarse sand	0.20 - 0.50	1:1.5 to 3
Loam	0.30 - 0.60	1:1 to 2
Clay	0.60 - 0.80	1:1 to 2

Note : Highest velocities and steepest side slopes are permissible in a well vegetated canal

The dyke should have a freeboard between 0.6 m to 1.00 metre to facilitate necessary maintenance operations. Possibility of floods should be considered for ascertaining the height of the dyke.

The method used for protecting a dyke will depend on the extent of protection desired and types of material used. A dyke should be seeded along the outer slope, at the top and along the inner slope upto the normal water line. This minimizes erosion and slumping and facilitates weed control. Locally suited permanent grass such as Vetiveria or Tussock may be advised as a surface cover. Appropriately graded rock, flat stone, precast concrete slabs, or some other suitable liners may be placed on the inside edge as a protection against wave action. Gravel can be used in conjunction with crushed rock or concrete mats to prevent erosion. Sometimes logs are also used for controlling bank erosion. Plants like waterhyacinth or duckweed may be grown along the pond margin for providing considerable amount of protection. These low-cost methods for checking dyke erosion have been found to be successful in many places.

b) Inlet Structure

Where wastewater is pumped or where sufficient head is available the inlet may discharge vertically upward. When wastewater contains large amounts of grit, the inlet should be on elevated pedestals, but the wastes must still be discharged below the water surface, for it discourages floatation of materials.

The inlet structure linking the grit chamber and the anaerobic pond or the first pond of the system can be a channel with rectangular or trapezoidal cross section, made of bricks or concrete depending on the working place.

The inlet channel can be constructed directly on the pond side slope, and care should be taken that the fluid flow must not erode the side slope or pond bed. To avoid this, the channel could be extended upto the bed level. Pitching on slope with bricks or boulders can also prevent soil erosion. Necessary provision should be made for diverting surface water around the ponds.

c) Pond Interconnection

The pond interconnections are one of the important structures of IWS system. They not only connect one pond with another but a properly built interconnector can also help in controlling the liquid flow. Wastewater ponds may operate either in parallel or in series or both. Therefore, the interconnections should have the facility to permit all such arrangements.

The interconnectors should be built in such a way that the wastewater can overflow from one pond to the other. An overflowing liquid also gives an idea about the quantity of flow. Different types of interconnector can be built. But it should be cheap and easily controllable. In many cases, pipes through the embankment are satisfactory interconnections provided that adequate precautions are taken to check dyke erosion. It can be accomplished fairly successfully if the connecting pipe discharges horizontally near the pond bottom.

For larger ponds the most common type is an ordinary masonry or stone culvert or a concrete box culvert with wooden shutter gates. Another type is a concrete pipe with controllable gates on either side. Provision of regulatory valves or other mechanical arrangements to regulate flow between structures may also be recommended. Interconnectors could be designed in several ways depending on the working place and availability of raw materials and the designer should choose the best suitable option for a particular pond system. The flow controlling gate can be made of cast iron, mild steel or simply from wooden planks.

d) Outlet Structure

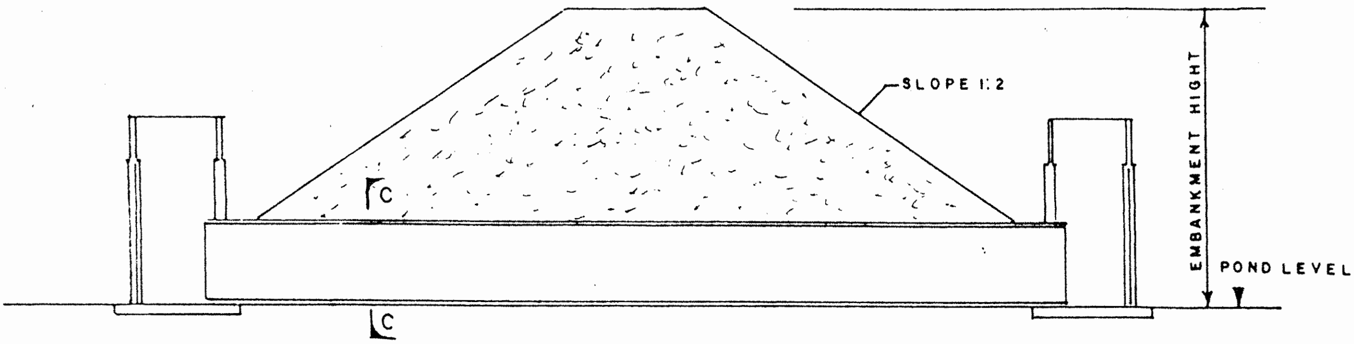
The design of the outlet structure will have to satisfy the following conditions :

1) overflowing effluent,
2) adequate sieving arrangement so that only water can flow out,
3) the floating materials should be prevented from being discharged by baffled outlets.

The outlet structure discharges into dry, intermittent or flowing waterways. Some outlets are designed to permit control of the pond level or to allow effluent to be drawn from various levels for regulating the quality of the effluent. Provision should be made in the design to ensure proper plant operation under all conditions of stream flow and discharge. The designer will have to know the frequency of floods and expected high flood level of the receptacle stream. Stream flow should never be allowed to enter ponds. Sluice arrangements can be provided for complete drainage of the pond where desired and where the levels permit. The outlet may be a structure similar to an interconnector with some minor modifications to fulfil the requirements.

Another simple and less expensive form of effluent collector is a pipe placed in the dyke at a desired elevation or a concrete spillway (with or without level controlling devices) constructed as an integral part of the dyke. Most outfall collectors are of the overflow-weir type. Broad-crested weirs constructed from wooden planks or concrete slabs can be used effectively to control the water level. A flow measuring device may be constructed separately or as an integral part of the outlet device. Sieving arrangements can be made with the help of bamboo, wooden sticks and fishing nets.

POND INTERCONNECTION DETAILS



SECTIONAL ELEVATION

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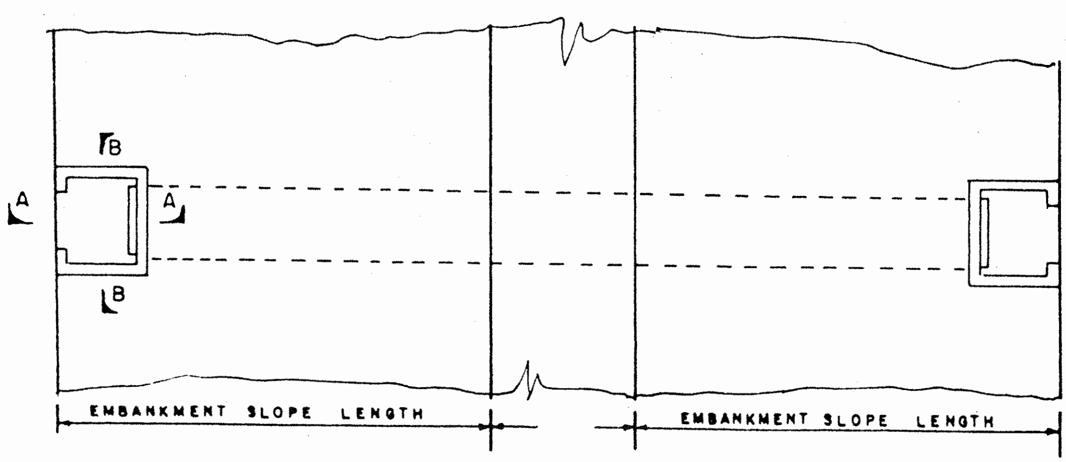

PLAN

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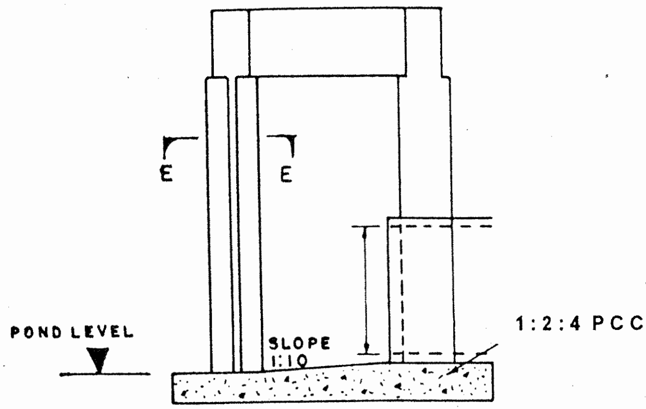
Figure -15

POND INTERCONNECTION DETAILS



SECTION-AA
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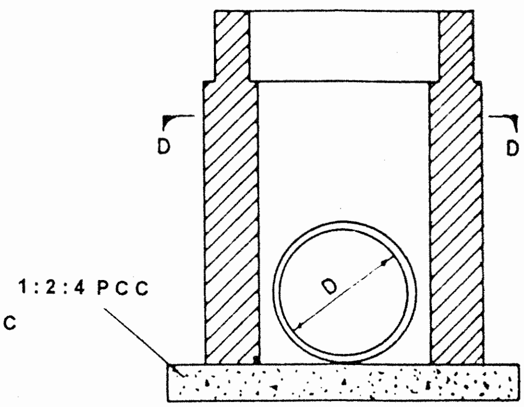

SECTION-BB
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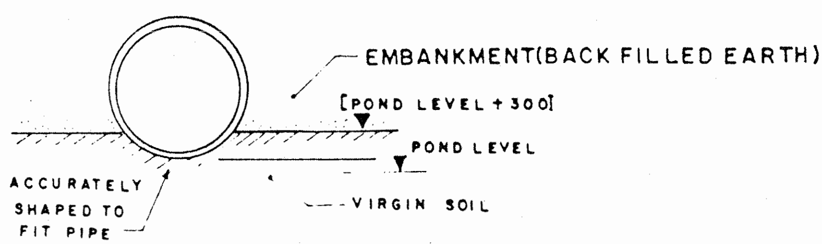

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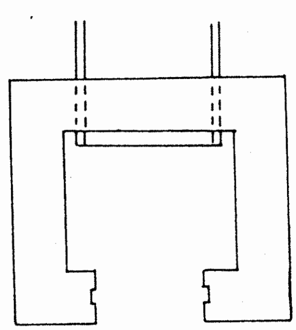

SECTION-DD
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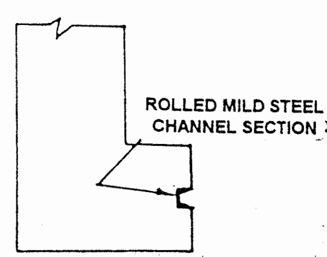


SECTION-EE
SCALE 1:25

Figure - 16

4.4 FLOW MEASURING TECHNIQUES

The performance of IWS projects depends considerably on appropriate flow measuring devices for wastewater influent and effluent. These devices need not provide continuous measurement and may be quite inexpensive. For example, a manhole on the incoming sewer and one in the effluent channel may be equipped to install a weir plate which can be easily slipped into its place during the periods of flow measurement. Flow measuring units should be located as close to the pond system as feasible and practicable but should not be placed in submerged portions of a sewer. The ideal location for placing a measuring device is just before the grit chamber.

There are several devices for measurement of flow of which the most common ones are described below. The choice of a particular type depends on specific circumstances and the accuracy needed :

A) Notches : These are cut from thin plates, and the forms are generally either triangular or rectangular.

1) Triangular notches : 90 degree triangular notches are used for measuring small quantities of flow varying from 0.008 m^3/sec to 1.25 m^3/sec. The discharge Q (in m^3/sec) for the 90 degree V notch is given by the expression :

$$Q = 2.362 \times Cc \times h^{2.5}$$

'h' is the measured head causing flow in metres and Cc is the coefficient of discharge and varies from 0.603 to 0.686 for the values of head varying from 0.06 to 0.377 m.

2) Rectangular notches : There are two types of rectangular notch viz., a) those with end contractions and b) those without end contractions. The limitations are same as those of a triangular notch. The width of the notch should be at least 150 mm.

i) Notches with end contractions : The discharge (in m^3/sec) through a rectangular notch with end contractions is given by the following equation :

$$Q = 0.667 \times Cc \times [2g]^{0.5} \times b_e \times H^{1.5}$$

Cc = varies from 0.58 to 0.72 for values of b/B between 0 to 0.8
b_e = actual width of the notch + k (value of k being 2.5 mm, 3 mm, and 4 mm for b/B ranges of upto 0.4, 0.4 to 0.6 and 0.6 to 0.8 respectively)
g = gravitational acceleration = 9.806 sq.m/sec
H = actual head measured + 1 mm
b/B = ratio of the width of the notch to the width of the channel

ii) Notches without end contractions : The discharge (in m^3/sec) through a rectangular notch without end contractions is given by the equation :

$$Q = 0.667 \times Cc \times [2g]^{1.5} \times b \times H^{1.5}$$

$Cc = 0.602 + 0.083\ h/p$
$H = h + 1.2$ mm
p = height of the bottom of the notch from the bed of the channel
h = actual measured head

B) Weirs : These are similar to rectangular notches but with considerable thickness in the direction of flow, so coefficient of discharge will be less. The weirs should be used only when the head is more than 60 mm. Minimum width of the weir should be 300 mm.

i) Weirs without end contraction : The discharge (in m^3/sec) equation is as follows:

$$Q = 0.5445 \times Cc \times g^{1.5} \times b \times H^{1.5}$$

Cc varies from 0.864 to 1.0 depending upon the H/p (ratio of measured head to length of weir in the direction of flow) value from 0.4 to 1.6, and for H/p values lower than 0.4, Cc may be taken as 0.864.

ii) Weirs without end contraction : The equation is same as that for a weir without end contractions mentioned before but instead of b the value of [b-0.1nH] should be taken into consideration. Here, n is the number of contractions.

iii) Proportional flow weir : This is a combination of a weir and an orifice. The sides are so curved that the area decreases as the three half power of the increasing depth of flow over the weir. Hence the rate of flow over the weir will vary directly as the head over the weir. This also maintains a constant velocity by varying the cross sectional area of flow through the weir so that the depth is proportional to flow. This weir is highly suitable if it could be placed just before a grit chamber as it helps to maintain a nearly constant velocity through the grit chamber. The weir should be set at such an elevation so that it provides a free fall into the outlet chamber as it cannot function under submerged conditions. Discharge Q in lps over the weir is given by the equation :

$$Q = 1570 \times C \times [2g]^{0.5} \times w \times H^{1.5}$$

where 'w' is the width of the opening at a height H in metres and C is the discharge coefficient (that may be taken as 0.6) and g is in m/sec^2. The depth may be made to vary directly with discharges if the value of '($wH^{0.5}$)' is kept constant. For different values of H, corresponding values of w can be determined and hence the parabolic curvature of the sides of the weir could be worked out. For practical purposes, the base of the weir may be limited to a convenient constant width for a small height over the crest, where the cross section is kept rectangular. The recommended value of this small height is 25 mm.

C) Flumes (free flow) : There are two types of flume.

i) Standing wave flume : In this type a standing wave of hydraulic jumps is formed down stream. The discharge (in m^3/sec) equation is given by :

$$Q = 0.667 \times [2g]^{0.5} \times C_f \times (Bo - m \times b - 2Cc \times m \times H) \times H^{1.5}$$

C_f = coefficient of friction having the following values:
0.97 for Q = 0.05 to 0.3 m^3/sec
0.98 for Q = 0.3 to 1.5 "
0.99 for Q = 1.5 to 15 "
1.00 for Q = above 15 "
Bo = overall throat width including piers
m = number of piers
b = thickness of each piers
Cc = coefficient of contraction, having a value of 0.045 for piers with round nose and 0.04 for piers with pointed nose
H = upstream head over sill corrected for velocity of approach = D_1 + Hv
D_1 = the depth upstream over sill of throat and Hv = $(Va_2)/15.2$
Va = the mean velocity of approach

ii) Venturi flume : For this, the discharge equation (in m^3/sec) is given by:

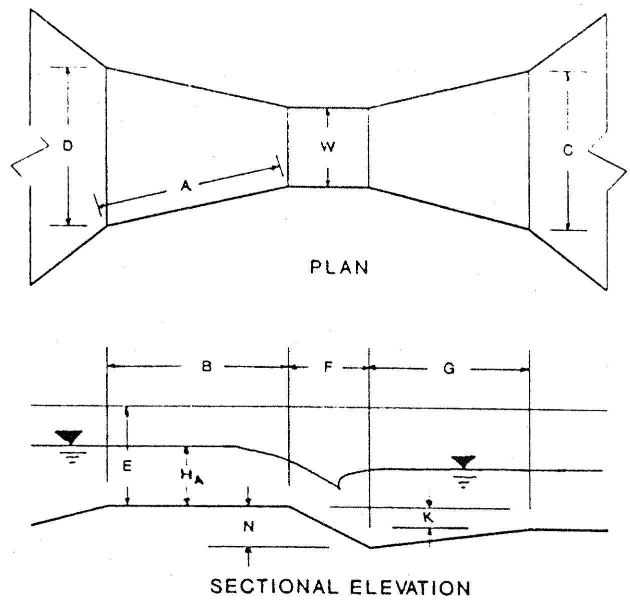
$$Q = 0.5445 \times Cv \times Cc \times g^{0.5} \times b \times H^{1.5}$$

where,
Cv = coefficient of velocity which varies from 1.04 to 1.15
Cc = coefficient of discharge varying from 0.885 to 0.99 depending upon H/l varying from 0.05 to 0.7 where l is the length of throat in the direction of flow.

iii) Parshall flume : Parshall flume is a type of standing wave flume which is widely used. It can be used both as a measuring device as well as a velocity control device similar to a proportional weir. The design velocity of flow (measured in lps) is given by the following equation :

$$Q = 2264 \times W \times Ha^{1.5}$$

where,
W = throat width in metres
Ha = depth of flow in upstream leg of the flume at one third point in metres. Recommended throat widths for different ranges of flow alongwith the dimensions of the various elements of the flume for different throat widths are given in the following table which should be strictly adhered to :



DIMENSIONS FOR PARSHALL FLUME
(REFER TABLE)
Figure - 17

Table - 5 : Dimensions of Parshall Flume (mm)

Flow range Qmax (Mld)	W	A	B	C	D	F	G	K	N
Upto 5	75	460	450	175	225	150	300	25	56
5 - 30	150	610	600	315	391	300	600	75	113
30 - 45	225	865	850	375	566	300	750	75	113
45 - 170	300	1350	1322	600	831	600	900	75	225
170 - 250	450	1425	1397	750	1010	600	900	75	225
250 - 350	600	1500	1472	900	1188	600	900	75	225
350 - 500	900	1650	1619	1200	1547	600	900	75	225
500 - 700	1200	1800	1766	1500	1906	600	900	75	225
700 - 850	1500	2100	2060	2100	2625	600	900	75	225
850 - 1400	2400	2400	2353	2700	3344	600	900	75	225

D = Full depth of flow (internal diameter); d = Actual depth of flow; V = Velocity at full depth; v = Velocity at depth 'd'; Q = Discharge at full depth; q = Discharge at depth 'd'; n = Manning's co-efficient at full depth; nd = Manning's co-efficient at depth 'd'

D) Drops : When a flow falls freely from a channel or conduit to a lower level the discharge can be roughly estimated at the point of drop through simple measurements. There should be a minimum straight length of 20 times the end depth in the approach channel. Minimum width of the channel should be of 300 mm. Critical depth Dc should be a minimum of 50 mm. The discharge (in m^3/sec) equation is as follows :

$$Q = Dc^{1.5} \times g^{0.5} \times b$$

where,

Dc = critical depth (in metres), and the ratio of end depth to the critical depth in horizontal and mildly sloped channels has a value of 0.7

b = width of the channel (m)

E) Orifices : Among various orifices, the drowned or submerged orifice is most suitable because the conditions for an ideal drowned orifice may be developed easily at the culvert type pond interconnections with gates or shutters. The discharge through a drowned orifice may be obtained from the following equation :

$$Q = 0.667 \times C_d \times b \times [2g]^{0.5} \times (H_2^{1.5} - H_1^{1.5})$$

where

C_d = coefficient of discharge (value between 0.6 to 0.9 depending on the type of opening)

b = width of opening

H_1 = height of water level from the bottom of the opening at downstream side

H_2 = height of water level from the bottom of the opening at upstream side

g = acceleration due to gravity

4.5 POND SYSTEM DESIGN

A facultative/recycling pond is a simple rectangular structure which stabilizes and purifies the sewage and traps nutrients. The purification takes places through physical, chemical and biological changes involving the action of algae and bacteria under the influence of sunlight (photosynthesis) and air. Three principal objectives of wastewater purification are :

a) removal and stabilization of suspended matter,

b) satisfaction of Biological Oxygen Demand and

c) reduction or elimination of pathogens as indicated by the coliform count.

Conventional pond system consists mainly of three types of pond depending upon the bacterial and algal activities. They are :

a) anaerobic pond,

b) facultative pond and

c) maturation pond.

In IWS system maturation ponds are termed as recycling ponds and for weak sewage even facultative ponds are used as recycling ponds to grow fish. The arrangement of the ponds is such that an anaerobic pond is followed by facultative and recycling ponds in series. In such an arrangement the entire sewage is treated under an anaerobic condition in the first pond. Anaerobic pond can be made upto 3 to 4 metres deep since algal photosynthesis is not important in this pond. About 60% to 70% of BOD is removed in this pond. Further treatment takes place in the facultative/recycling pond which is shallow and less than 1.5 metres in depth. The rate of anerobic decomposition increases with time, reaches a maximum value and then decreases. The rate of aerobic decomposition is propotional to the remaining undecomposed organic matter. The higher the detention time, the more is the rate of decomposition in the aerobic pond. This distinguishes an aerobic pond from an anaerobic pond.

The effluent BOD of wastewater from a recycling pond can be expressed as :-

$$BODe = BODi \times (1 - 10^{-kt})$$

where, BODe = Effluent BOD; BODi = Influent BOD; t = detention time in the pond. To calculate the BOD satisfied in a facultative/recycling pond or the remaining BOD in the effluent from this pond, it is desirable to know the value of the first order reaction constant 'k'. Generally the value of 'k' varies from 0.05 to 0.3 depending on the various parameters. Under Indian conditions, at 20°C for domestic sewage the value of 'k' may be assumed to be 0.1 per day (base 10). Other than 20°C of ambient temperature, the value of 'k' at temperature t°C is as follows: $k_t = k_{20} \times O^{(t-20)}$. Value of O is 1.056, when temperature is between 20°C to 30°C and 1.135, when temperature is between 4°C to 20°C.

The factors such as rainfall, evaporation, solar radiation in the form of sunshine, sky clearance factor, temperature, prevailing winds, etc. should also be considered. The amount of sunlight received by a pond depends upon its area, the intensity of radiation received at that latitude and altitude, the degree of cloudiness and other metereological features. Preference should be given to the sites that permit unobstructed wind action on the water surface. Direction of flow in pond should preferably followed the direction of wind. If ponds are so oriented that their longer dimensions are parallel to the direction of local prevailing winds maximum wave action will be attained. Wind action improves the light utilisation efficiency of algae by inducing mixing. The utilisation of the solar energy by algae (by photosynthesis) results in generation of new algal cells and production of oxygen which is necessary for bacterial decomposition of the organic matter contained in sewage. A very high intensity of light is not needed for successful waste treatment. Adequate light energy is normally available anywhere in India and other tropical countries. The light energy received on a horizontal surface is depicted in langleys (calories/cm^2) per day. The approximate corrections in light energy received for elevations upto 3050 m are as follows :

a. Corrected total radiation = Total radiation at sea level x (1 + 0.0607 x EL)
b. Corrected visible radiation = Visible radiation at sea level x (1 + 0.0304 x EL)

where, El = Elevation above sea level in thousand metres.

Sunlight cannot penetrate very deep into pond waters and hence algae tend to flourish mainly in the upper layers. For this reason the depth of facultative and maturation pond should be restricted to 1.5 metres. Rainfall is generally not taken as a parameter in the design because of the reason that although rainfall implies cloudy weather and reduction in solar radiation but the degree of dilution at that time is correspondingly high and hence the rainy season does not constitute a critical period. Temperature is generally an important parameter because the value of reaction constant 'k' is dependant on it.

Allowable organic and hydraulic loading rates are also important for designing a stabilisation pond system. There exist allowable surface loading or volumetric loading values for different ponds. For an anaerobic pond the volumetric loading should not exceed 400 $gm/m^3/day$ so as to maintain an anaerobic condition and avoid odour nuisance. In winter it may be about 300 $gm/m^3/day$. Therefore, the design volume of anaerobic pond can be expressed as :-

Volume = Flow of wastewater x BOD of wastewater / Volumetric loading

The allowable surface loading for a facultative pond can be determined by the factors mentioned above.

As an example, consider the following parameters :-

Latitude of a place = 22° N
The mid-depth area of facultative pond = A_f hectares
The average depth of facultative pond = D_f metres
The total sewage flow = Q Mld = 1000 x Q m^3/day
BOD of the sewage = S mg/l = S / 1000 kg/m^3
Maximum solar radiation = 174 langleys/day = 174 calories/cm^2/day.
Minimum solar radiation = 123 langleys/day = 123 calories/cm^2/day
Sky clearence factor = 60%

Therefore, average solar radiation
= Min + [(Max - Min) x sky clearence factor]
= 123 + [(174 - 123) x 0.6] = 153 calories/cm^2/day = 1.53×10^{10} cal/hectare/day

At sea level, the level correction = 1.0

In the above condition, it has been assumed that bacteria and algae are in abundance. As they are symbiotic, we have to find the amount of algae and the oxygen released. Energy stored in algal cell at 6% efficiency
= $1.53 \times 10^{10} \times 0.06$ = 9.18×10^{8} cal/ha/day

Total energy provided per day for algal growth = $9.18 \times 10^8 \times A_f$ calories/day
Heat of combustion of algae = 6.00×10^6 calories/kg
So, the weight of algae produced per day = $9.18 \times 10^8 \times A_f / 6.00 \times 10^6$
= $153 \times A_f$ kg/day
The ratio of weight of oxygen released by algae to the weight of the algae = 1.64
Therefore, oxygen released per day = 153 x Af x 1.64 = $250.92 \times A_f$ kg/day
And BOD, which can be removed per day = $250.92 \times A_f / (1000 \times Q)$ kg/m^3
= 0.251 x Af / Q kg/m^3

The mid-depth area of facultative pond required for one day detention of sewage
= $1000 \times Q / D_f$ m^2 = $0.1 \times Q / D_f$ hectares
Therefore, in one day the amount of BOD which can be removed
= $0.251 \times 0.1 \times Q / (D_f \times Q)$ kg/m^3 = $0.0251 / D_f$ kg/m^3 = 251 kg/hectare

Therefore, maximum allowable surface loading that the pond can handle in a day
= 251 kg/hectare/day

Therefore, the design mid-depth surface area of facultative/recycling pond can be expressed as :

Area = Flow of wastewater x BOD of wastewater / Surface loading

The pond should be of a shape and size that will ensure an even distribution of the load over the entire pond area. The shape should be such that the sewage can mix and quickly can be evenly distributed to prevent development of local septic areas. A uniform flow through the pond must be assured; this means that the shore line should be regular with no indentations

Removal of faecal coliform bacteria is one of the important features of the stabilisation pond. The reduction of faecal bacteria in a pond has been found to follow the first order kinetics. The equation of reduction is as follows:

$$Ne = Ni / (1 + [K_b \times t])$$

Where,

Ne = number of faecal coliform / 100 ml of effluent
Ni = number of faecal coliform / 100 ml of influent
Kb = first order reaction constant & v of faecal coliform removal constant per day
t = detention time in days

The design should permit maximum flexibility and control of operation of the ponds. There hould be flexibility in relation to depth, provision for recirculation, arrangement for parallel or series operation, and design so that one or more ponds can be taken out of service without affecting the remaining ones.

4.6 ESTIMATING IRRIGATION DEMAND

Irrigation demand (during non-monsoon period) is the sum total of consumptive use of water by the crops and the unavoidable loss that takes place. Consumptive use of water is estimated by adding up the amount of water used in the metabolic process and the loss that takes place due to evapotranspiration. Unavoidable loss is the amount lost beyond root zone. The factors which influence the water requirement of a crop include :

1) crop and its variety
2) soil type
3) climate
4) fertility status

It will be possible to collect relevent crop-wise information from local agricultural office. A brief discussion of the above factors influencing the water requirement of a crop follows :

crop and its variety
Water requirement of a crop depends on the leaf area index and height of the crop.

$$\text{Leaf are a index} = \frac{\text{Total leaf area}}{\text{Total land area}}$$

soil
The requirement of water is influenced by the rate of water movement through soils. The higher the rate of movement the higher is the rate of requirement of water. That is why crops grown on sandy soil, which has higher hydraulic conductivity, will always need more water than the same grown on clay loam. Clay loam can retain fair amount of moisture even at higher moisture tension while sandy soil may dry out in comparable conditions.

climate
Climatic factors will include radiation, vapour pressure deficit, wind velocity, temperature and sunshine hours. There are working guidelines to relate climatic factors with water requirement for different crops.

ferility status
An increase in the nitrogen level increases the leaf area index alongwith the depth and spread of root system of the crop. This entails increase in consumption of water.

5. OPERATION AND MAINTENANCE : A USER BASED APPROACH

5.1 O & M OBJECTIVES

The O & M programme for IWS projects aims at meeting the dual need for wastewater treatment and recycling. Engineering equipments and appurtenances in IWS projects should be simple but the O & M schedule will have to be rigorous and reliable.

O & M requirement will, to some extent, be location specific. Developing specific O & M programmes for different IWS projects will include preparation of an O & M schedule, an implementation plan for this schedule and user's handbook.

5.2 PRE-PROJECT QUESTIONS

In many cases, O & M questions are overlooked during the design stage and serious unforeseen problems of maintenance crop up subsequently. A set of questions is arranged to reduce the unpredictability.

1. Anticipated flow
   a) average flow
   b) peak flow
   c) seasonal flow variation

2. What are the plans for mitigating flood impact on the project site and the surrounding areas ?

3. What is the expected time of construction ?

4. How will the flood be measured ?

5. How will the flow be regulated through the system ?

6. What is the status of sewerage system connecting the IWS projects ?

7. What are the plans for dyke plantation/vegetation ?

8. How frequently will the waste quality be measured ?

5.3 PREPARATION OF PONDS AND START UP PROCEDURE

It is wiser to carry out pond preparation activities in dry seasons and allow a start up time when microbial enrichment is rapid. Major steps involved in pond preparation include:

* drainage of pond
* solar drying
* desilting
* tilling

Ponds can be drained by either releasing the water through the outlet by gravity or by pumping or in many cases by both. It will be wise to harvest as much fish as possible before the water is drained out.

Solar drying is the simple system of allowing the pond bed to dry up naturally. The process reduces fungal load, helps the movement of atmospheric nitrogen in the soil and enriches the substrate. It is necessary that the soil of the pond bed cracks.Otherwise a gradual loss of productivity is likely to occur. However, local farmers of the East Calcutta wetlands do not always share this view and do not always wait for the pond beds to crack before introducing wastewater into the pond.

Desilting of silt traps is required (figure - 18) which are generally three metre wide and 50 centimetre deep and are excavated around the periphery of the pond to allow the silt to be trapped in them. However, some ponds may not have silt traps.

SECTION SHOWING THE EDGE OF THE POND

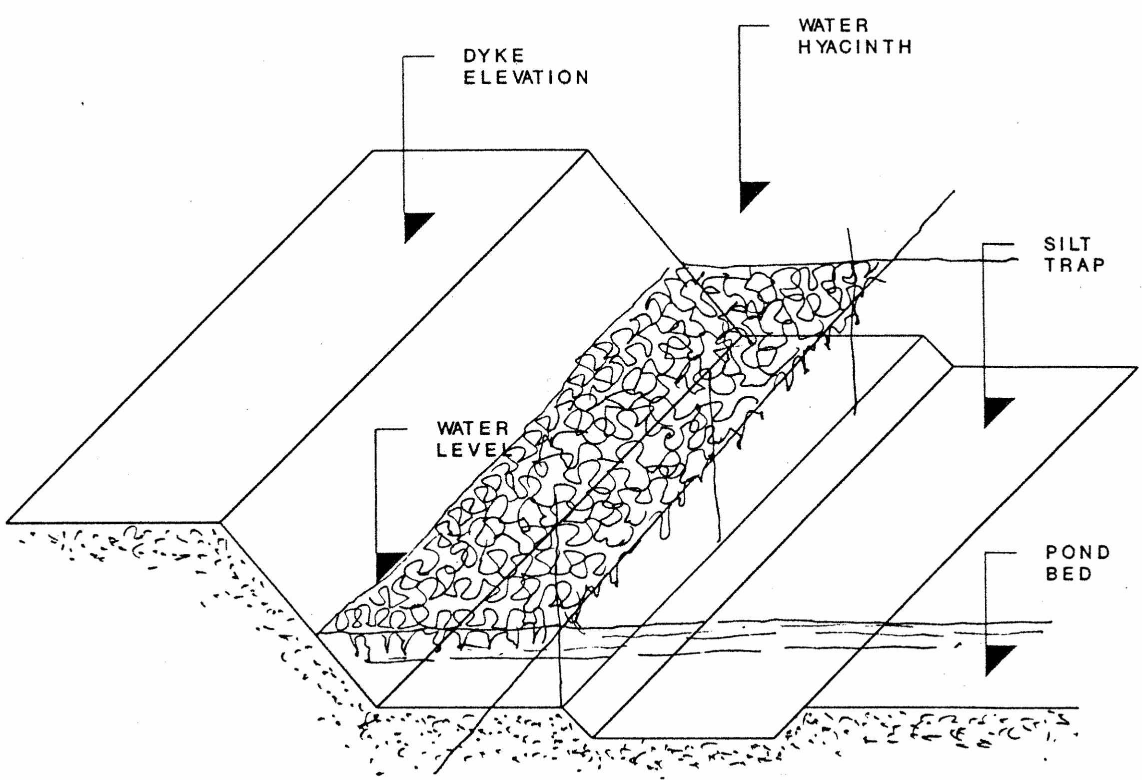
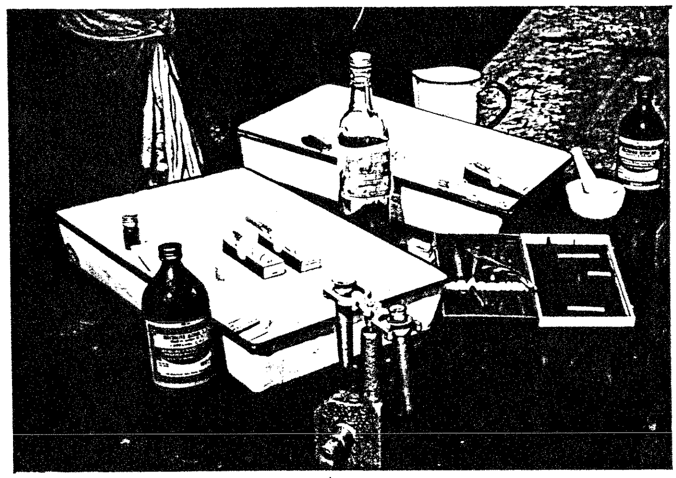


Figure - 18

Tilling of the pond bottom is necessary for the following three reasons:

a) decomposition of organic deposits at the bottom,
b) eradication of some undesirable cyst in the subsoil and
c) releasing the trapped gases and allowing the bottom dwellers a better crawling surface.

Simple tools and equipments for measuring water quality.



Pond Management

Introduction of wastewater in the pond is equivalent to application of fertilizer for stimulating the growth of algae and plankton. Primary productivity of the pond increases with the release of nutrient elements from wastewater. Initial loading of the pond should be done in stages and depth of sewage should not exceed 30 cm in any occasion.

Anaerobic Ponds

It is observed that all anaerobic actions consist of two phases. In the first phase, organic matter gets reduced to organic acids, malodorous organic compounds, ammonia and hydrogen. The next phase is called the gasification phase in which the organic acids get converted into methane. The conversion results in a high degree of organic matter removal.

To bring a new anaerobic pond in operation, it is customary to use an admixture anaerobic sludge and cow dung. The methano-bacterium in the dung establishes itself in the pond and produces methane gas. At the beginning, the anaerobic pond should be loaded gradually over a couple of weeks up to the design loading rate. Care should be taken to maintain the pond pH above 7 to permit the development of methanogenic bacteria and it may be necessary during the initial months to treat the pond with lime or soda ash.Sometimes it may be necessary to apply lime regularly in an anaerobic pond during the operation. In the newly sewered towns where availability of sewage is low, it is best to by-pass the anaerobic pond until the sewage strength and flow ensure a loading of at least 100 grams/cubic metre/day.

Recycling Ponds

For a recycling pond, a depth between 1.0 and 1.5 metre is advisable so that the top layer acts as an aerobic zone and the bottom anaerobic.

Initially when the sewage is loaded in the pond, the stagnation of waste allows algae to grow and further addition of waste results in algal bloom. The initial stagnation period may vary from three to four weeks. Release of an odour is inevitable during this period.

A facultative or recycling pond cannot immediately receive its full BOD or hydraulic load. Firstly, algal growth is not as rapid as the growth of bacterial population; secondly, the degraded materials take time to seal the pond bottom and thirdly the full loading calculated on the basis of total population for which the pond is planned, may not be obtained immediately at the beginning. This will gradually increase as more sewer connections are made.

Normally the ponds are filled in stages.There is another method where the facultative pond is filled as rapidly as possible with wastewater to a depth of 1.0 metre and then left undisturbed for a period of 10 to 20 days or until the water turns greenish or bluish-green. The allowable surface loading should not be exceeded in which case the green algae may be replaced by foul smelling blue-green algae and the surface water may become gray or pink in colour.

In case of malfunctioning of the pond caused due to continuous overloading, a part of the wastewater should be made to by-pass the pond for some time till it recovers from the effects of overloading. The floating mat of scum that is found when blue-green algae predominate, must be removed. A net with a long handle can be used for this purpose. The floating scum is likely to form on the surface of a pond in winter when fermentation rates are low.

5.4 COMPONENTS OF O & M MODULE

O & M module of IWS projects include following components :

1) maintenance of the levels of water in the pre-treatment and recycling ponds
2) wastewater pressure mains
3) release of system effluent to the best satisfaction of the downstream users
4) appropriate recruitment and harvesting schedule for recycling ponds adjusted to the condition of wastewater loading
5) maintenance of structures, appurtenances and equipments
6) periodic desilting of pond beds
7) maintenance of conduits and peripheral drains
8) maintenance of dykes and dyke gardens
9) evaluation and monitoring of user region ecosystems
10) reducing risk through an early warning system.

A separate guideline for O & M activities specific to each project site may appropriately be prepared after the construction work begins. Without adequate attention towards local issues it will not be appropriate to properly define or recommend detailed O & M tasks. It will however be possible to elaborate a little more on the above components of O & M module.

Maintenance of water level can best be done by clearly indicating the permissible depth of loading somewhere within the pond. Placing pole at the centre of the pond should be avoided to facilitate the harvesting operations.

Wastewater pressure main connecting the pumping station and grit chamber inlet needs careful supervision. It is easier to plug the smaller leaks than to allow the situation to go grow worse.

Release of system effluent is a highly sensitive O & M task when the effluent is used for downstream irrigation. It will have to accord with the need of the users and at the same time an excess storage or a water shortage in recycling ponds has to be avoided.

Appropriate recruitment and harvesting schedule is one of the most important O & M components in IWS projects. The schedule will be region specific and will depend upon the skill of the fish grower engaged in the work.

Maintenance of structures, appurtenances and equipments is a routine activity and can be easily pursued through a systematic monitoring. This is carried out with the help of a daily visual inspection schedule given herein.

Periodic desilting of pond beds will depend on the pond size, fish stock and local conditions. Smaller ponds (less than 10 hectares) should preferably be desilted every year.

Maintenance of conduits and peripheral drains is necessary to avoid flooding within and outside the project area. An alert surveillance can easily take care of this responsibility.

Maintenance of dykes and dyke garden is an integral part of the day to day O & M activity. In absence of a boundary wall this work assumes particular significance. For projects surrounded by (totally or partially) human habitation, there is a strong tendency of the local people to damage the dykes.Permanent dyke surfacing by concrete or stone is a costly proposition. A method of using a hyacinth margin to reduce erosion has developed in the East Calcutta wetlands and is an interesting example of creative management.

A special survey may be initiated to obtain recommendations for the type of dyke garden that is expected in the project area. On a 15 hectares of dyke area more than 100,000 trees have been planted by the members of the Mudialy Fishermens' Co-operative Society.

Members of the Mudialy Fishermen's Co-operative have planted more than 100,000 trees on a 15 hectares dyke space.

Evaluation and monitoring of user region ecosystems are necessary for sustenance of IWS projects. Appropriate distribution of the system effluent amongst beneficiaries who are interested to irrigate their farms with the help of this new supply of water will establish firmer roots amongst the local people and stimulate stakeholders' participation in the project.

Reducing the risk through an early warning system is, in practice, an activity to keep the system in readiness to meet the perturbing forces. These forces can be in the form of floods or perhaps public wrath in sharing irrigation water.

5.5 PROJECT MONITORING AND RECORD KEEPING

The importance of project monitoring and record keeping can hardly be overstressed. This task will have to be carried out with the help of standard schedules. After the project is commissioned it will be possible to develop appropriate schedules and improve them from time to time. At present two basic schedules are described for use in the initial working months.

Vegetables are grown on garbage dumps. These plots are irrigated with effluent coming out of wastewater fish ponds.

A. VISUAL INSPECTION SCHEDULE

1. Flow : a) Peak.................................. b) Average ....

2. Rainfall ....mm

3. Cloudiness...(in hours)

4. Temperature : a) Air.. b) Water...

5. Pump house details :
   - i) Duration of pumping and number of pumps used (with rated capacities)..
   - ii) Electrical unit consumed..
   - iii) Pump operator's remarks..

6. Condition of dykes :
   - i) Erosion..
   - ii) Excavation..
   - iii) Damages to plantation..
   - iv) Leakage..
   - v) Tree population and species diversity..
     ....

7. Pre-treatment facilities (status of maintenance)
   - i) Grit chamber..
   - ii) Anaerobic pond..

8. Project roads :
   - i) Surface condition..
   - ii) Special problems..

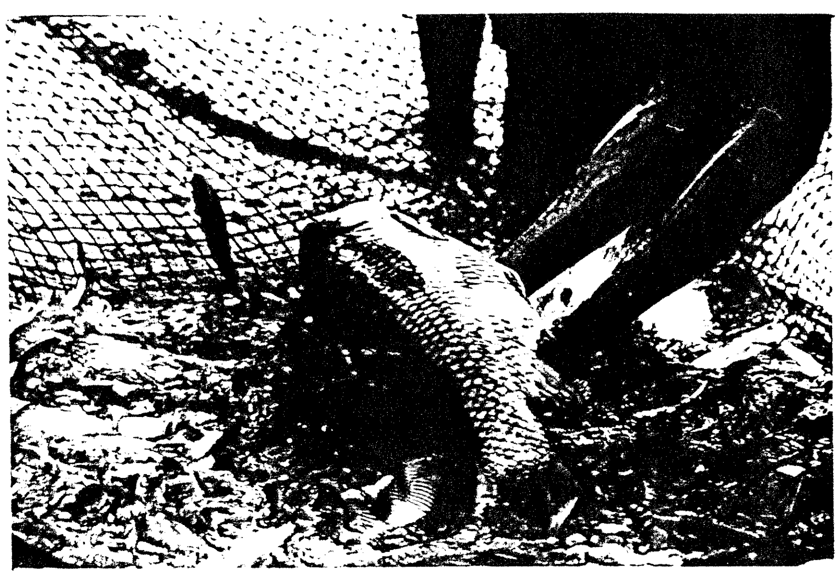
9. Ponds (to be observed and recorded separately for each pond) :
   - i) Color..
   - ii) Odour..
   - iii) Water level..
   - iv) Scum..
   - v) Aquatic macroflora..

10. Regulatory structure :
    - i) Regulatory gates..
    - ii) Inlet and outlet construction..

B. EFFLUENT MONITORING SCHEDULE

Characteristics	Items to be monitored	Frequency
Water Quality	BOD	Bi-monthly
	COD	Quarterly
	Fecal coliform	-do-
	Total coliform	-do-
	Nitrate (NO_3)	-do-
	Un-ionized ammonia	-do-
	Residual chlorine	-do-
	Metals (lead, iron, mercury, cadmium, arsenic etc.)	-do-
	Orthophosphate	-do-
	Total phosphorous	-do-
	Chloride	-do-
	Nutrient	-do-
Water regime	Precipitation, Water budget, Time of Residence	Daily

These fishes are grown in wastewater in the wetlands of Calcutta. They have been found to have less pathogens than the similar ones grown in fresh water village ponds.



5.6 HEALTH RISK

It has been observed that aquaculture as a wastewater recycling process has much less health risk than that in agriculture. In fact introduction of aquaculture before using the wastewater for irrigation is a comprehensive safeguard against pathogen contamination. Fish is not a natural habitat for human pathogens. Furthermore, the habit of eating fish fried deep go a long a way to eliminate the health risk.

In the Department of Bio-Physics, Molecular Biology and Genetics of the University of Calcutta an interesting observation has been made on this question of pathogen contamination from sewage grown fishes. The study compared the bacterial content in fish grown in wastewater fishponds of East Calcutta and that grown in normal village ponds not fed with wastewater. Repeated observations have conclusively shown that the so called fresh water ponds in villages are worse in terms of their bacterial content compared to wastewater fishponds of East Calcutta.

It is also necessary to introduce the concept of 'relative risk' assessment in place of conventional approach of assessment of 'absolute risk'. For the communities in South Korea or Japan who eat raw fish, the permissible concentration of 10 coliforms per 100 millilitres of water in fish ponds sounds appropriate but the same standard for places like India, where fish is invariably fried deep before consumption, does not apply and the relative risk is much lower.

The problem of health risk that may be linked with wastewater utilisation in fisheries and agriculture cannot therefore be properly understood without a comparative assessment of such risks to which the target communities are exposed. This can be done by using the same indicators to assess the risk of eating all the major food items commonly consumed by the target communities. The resultant matrix of risk values against all the major food items will correctly depict the level of risk that a particular item of food may be causing relative to other agents of contamination.

5.7 CHOICE OF SPECIES

Wastewater ponds present a typical ecosystem condition that is suitable for a selected group of fish species. The criteria for choosing such species should take the following things into account :

1. tolerant to low (about 0.5 mg/l) and fluctuating (0.5 to 20 mg/l) levels of dissolved oxygen.

2. fishes which graze on phytoplankton are more efficient in energy utilisation eg. (*Hypopthalmichthys molitrix*)

3. fishes grazing on detritus or which are detritivorous

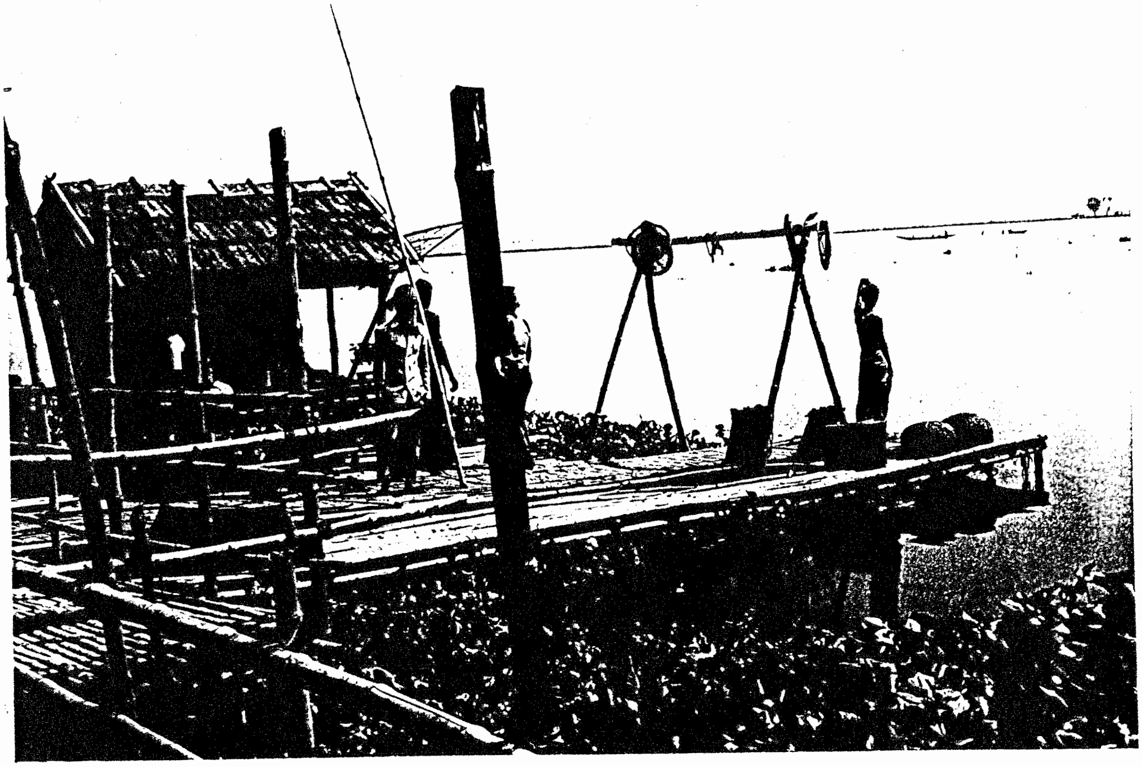
4. fishes which are omnivorous are suitable at all levels of the water column

5. fishes which are tolerant to types of pathogen present in the wastewater (fishes are not a natural habitat for human pathogens).

A selection of fishes which are suitable for growing in wastewater ponds is shown in the following table :

Table 6 : List of Selected Fish Species Grown in Wastewater Ponds

Sl. No.	Name of the species	Characteristics
1	Cyprinus carpio	Highly suitable in wastewater ambience; can tolerate D.O. levels less than 0.5 mg/l and can adopt wide D.O. fluctuation.
2	Hypopthalmicthys molitrix	Most efficient in using primary products like phytoplankton; it can control algal blooms.
3	Indian Major Carps a) Labeo rohita b) Catla catla c) Cirrhina mrigala	 Zooplankton eater Zooplankton eater Detritivous
4	Air breathers a) Clarias batracus b) fossilis	Unaffected by DO depletion and can be easily grown in wastewater ponds
5	Shrimps and prawns	Prawns are highly sensitive to allow DO level and are not advisable for culture. However a small number of shrimp population may be retained as an indicator for DO problem



A typical fish landing jetty in Calcutta wetlands. From here the harvest is transported to the auction market.

In the wastewater fishponds of Calcutta Tilapia nilotica was successfully introduced by local fishermen.

6. CONDITIONS OF SUSTAINABILITY

6.1 UNDERSTANDING THE TASK

Threats to the sustainability of the IWS project are mainly anticipated from:

* constructional damages due to flooding or excess storage
* disagreement on the interest of the local people and the stakeholders
* reduced economic viability of resource recovery practices.

Accordingly, the task of ensuring sustainability will have three components :

* safeguarding the constructions
* facilitating stakeholders' participation and
* upgrading resource recovery system

TASK OF ENSURING SUSTAINABILITY

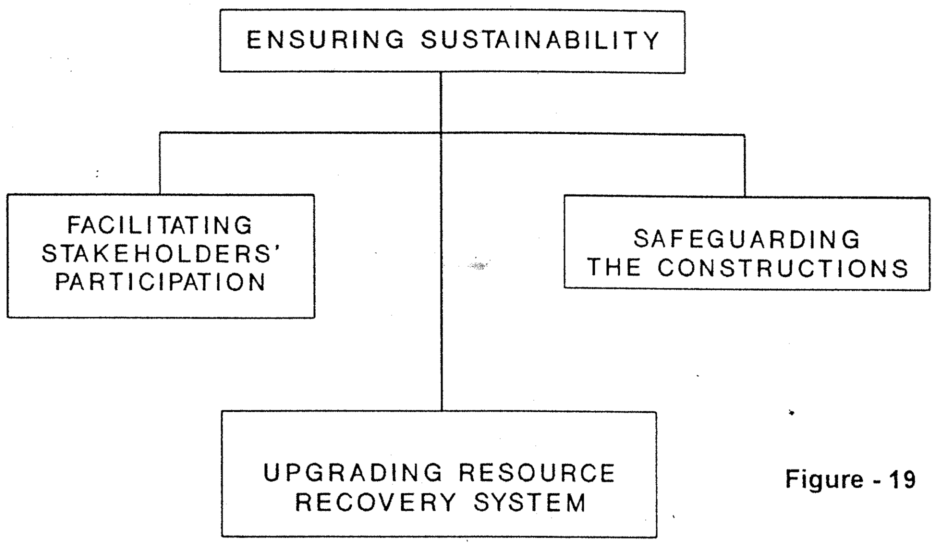
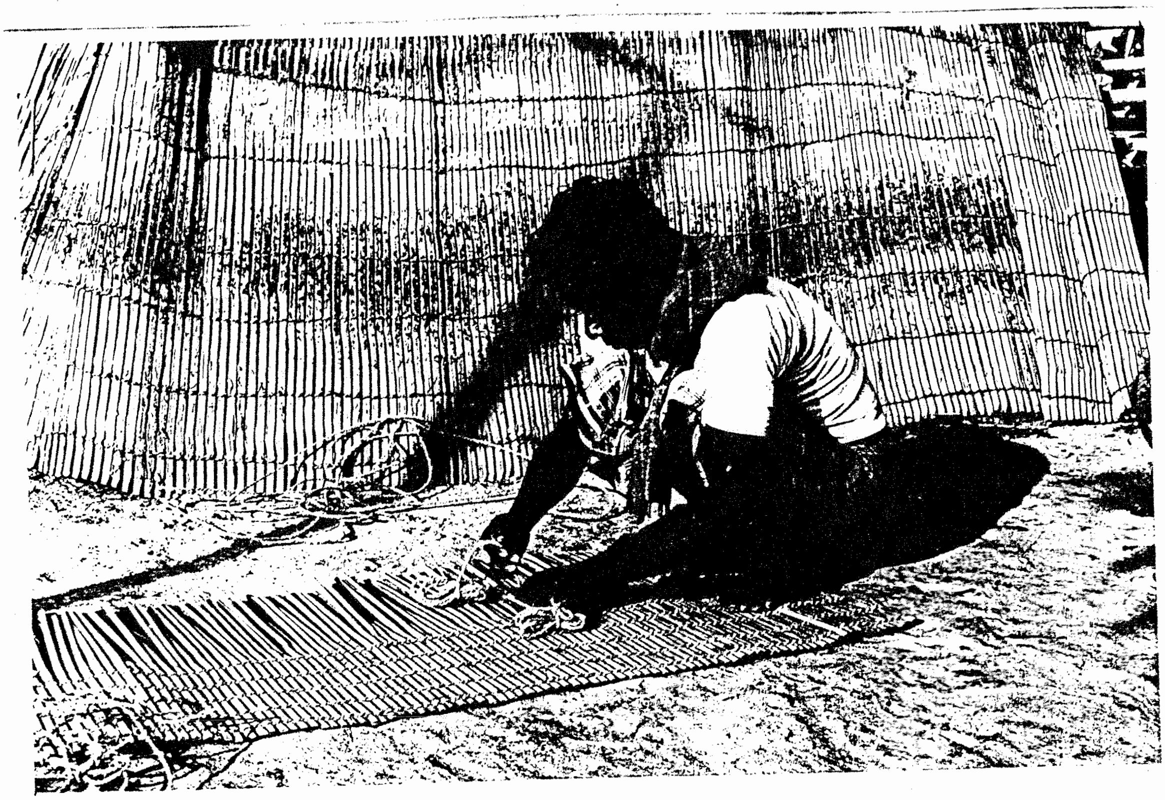


Figure - 19

Safeguard against flooding is the most important condition of sustainability of the project and it has appropriately been discussed in the chapter on project design. A number of activities in support of the remaining components are listed below. These activities, in many cases, contribute to more than one of the three basic tasks for ensuring sustainability and have not therefore been grouped separately. These activities can be described as :

* enhancing downstream utilisation and creation of job opportunity
* providing facilities for education on environment and ecology
* developing recreational facilities
* diversification of products and species
* improvement of yield at sustainable levels
* resolution of conflict



Indirect job opportunities in wastewater fisheries are nearly equal to direct job opportunities.

Dykes are protected by water hyacinth margins. Simple techniques are used to stop grazing of cattle on the dyke.

6.2 MAJOR ACTIVITIES

Effluent Utilisation

1. At the beginning it will be necessary to know the amount and the quality of effluent that is available from the project and about its existing use.

2. The use may then be evaluated on the basis of the strategy outlined in chapter - 3.

3. In case the effluent is not adequately used it will be necessary to identify additional areas where it may possibly be utilised. Such user areas should preferably be close to the receptacle channel.

4. The task of identifying new user region will have to involve and be guided by local people and authorities. In case there is a lack of motivation among the local people and stakeholders it will be important to sensitize them about the significance of IWS projects in general and effluent utilisation in particular.

5. The task of identification can be best accomplished by carrying out a need assessment survey with the help of selected local people who are more advanced and articulate. A comprehensive plan for effluent distribution can then be made on the basis of the above survey.

In a prawn culture area 30 kilometers east of Calcutta the fish producers have started appreciating the importance of wastewater introduction in the lagoons. The prawn is exported under stringent qualitative tests.

STEPS FOR ENHANCING DOWNSTREAM UTILISATION OF POND EFFLUENT

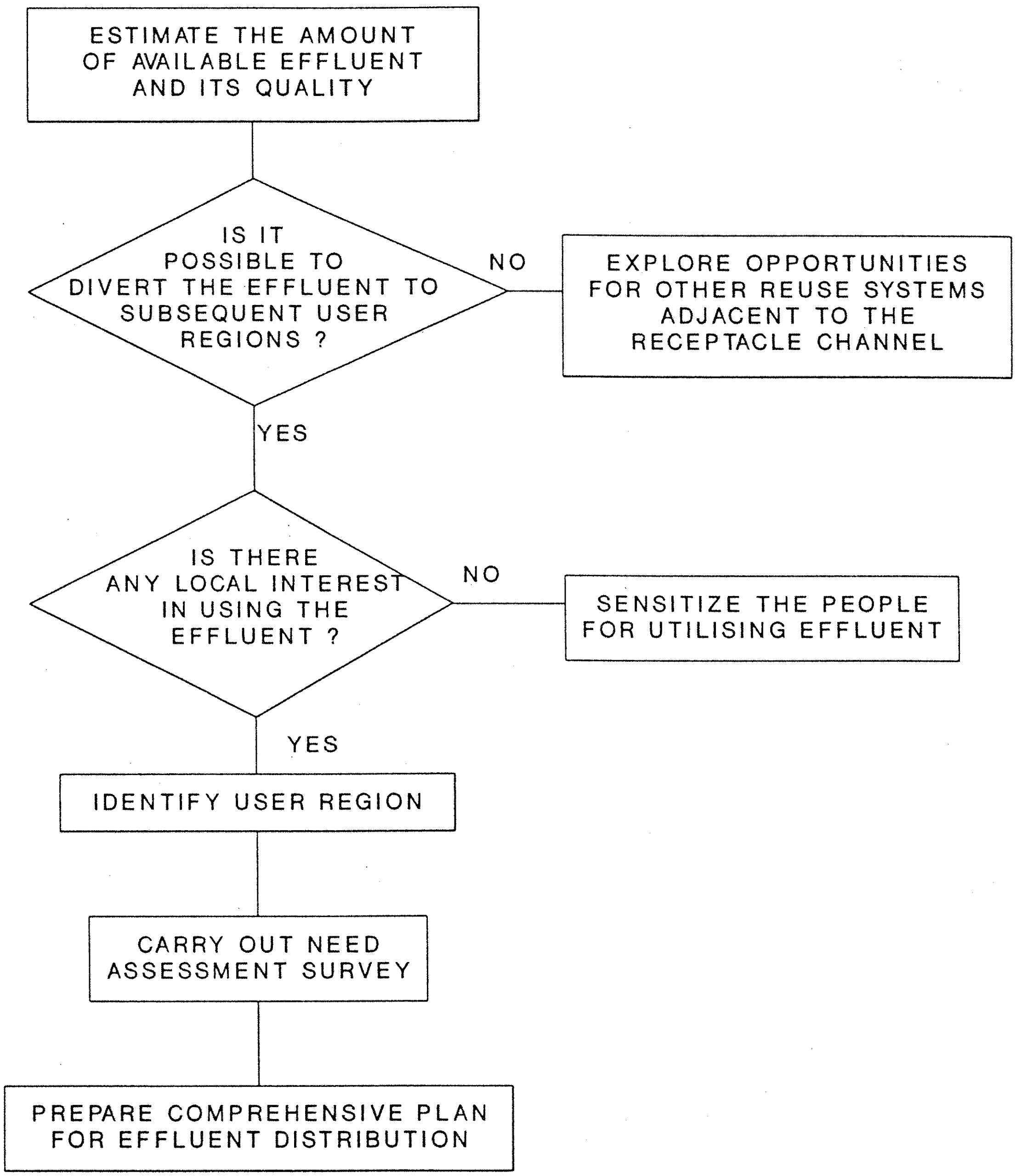


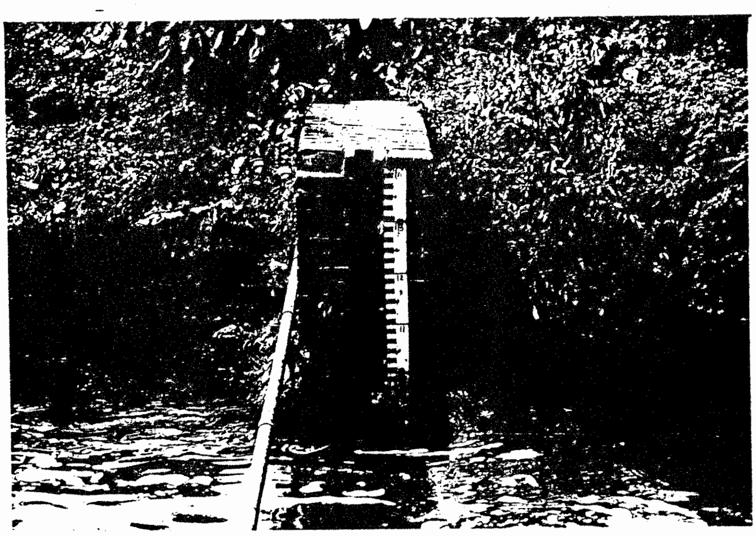
Figure - 20

Environmental Education

Inclusion of educational facilities within the IWS project is a new approach to make local beneficiaries aware of the significance of these projects. IWS project areas are potential sites for tutorial ecosystems because of the interesting nature of wetland use and ecological manipulations introduced to run the system. The increasing need for environmental education and awareness makes the educational component of IWS project particularly relevant.

To start with it will be necessary to outline the programme contents based on the opportunities available at the specific project site. This will be followed by identifying target groups. Each target group will be provided with separate programmes.

Local institutions should preferably be identified for various supporting functions. In absence of an appropriate school or college it will be necessary to find out the nearest institution for obtaining necessary facilities. Initially simple curriculum outline can be a good beginning. This will subsequently be followed by more detailed ones and national or international funds can be drawn to strengthen the programme. A properly written programme circular with faculty description can even bring outstation participation and such educational programmes can be profitably run by the IWS project authorities.



Simple techniques for managing hydraulic regimes

STEPS FOR INTRODUCING EDUCATIONAL FACILITIES

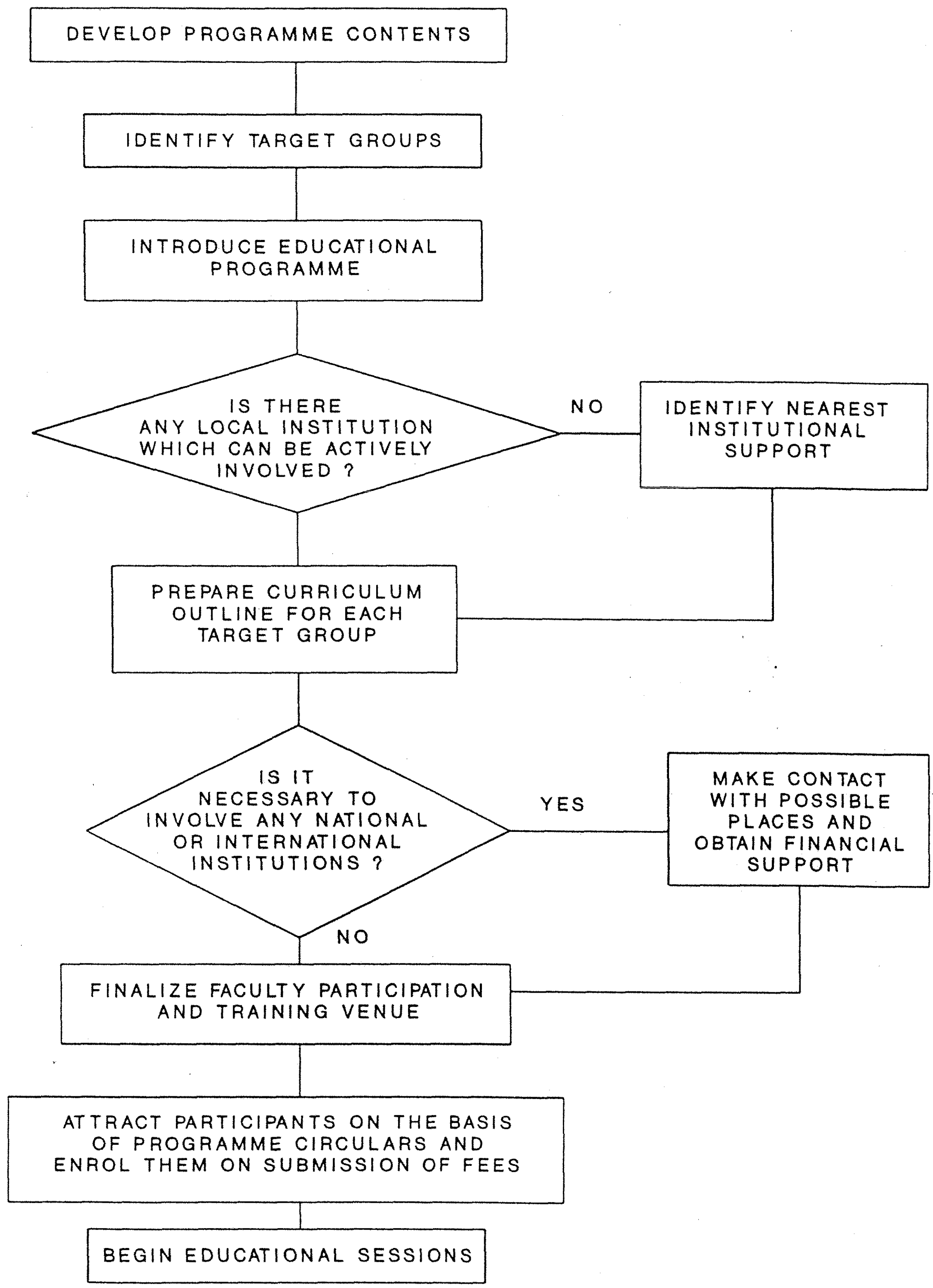


Figure - 21

Recreational Facilities

Being large water areas, IWS project sites are likely to draw visitors. An organized approach can transform the sites into excellent locations for recreational activities and more people can benefit from the project. It is nessecary to identify the project boundary and demarcate the areas where visitors will not be allowed to enter. A rapid survey of local recreational need will help in planning the facilities. In some cases these can be paid facilities which add to the viability of the programme in general. The facilities should be extended in a phased manner to avoid sudden overcrowding. It is also necessary to set up appropriate display boards carrying important notices (figure - 22).

For any age group, fishing is one of the oldest recreational opportunities provided by the waterbodies.

STEPS FOR CREATING RECREATIONAL FACILITIES

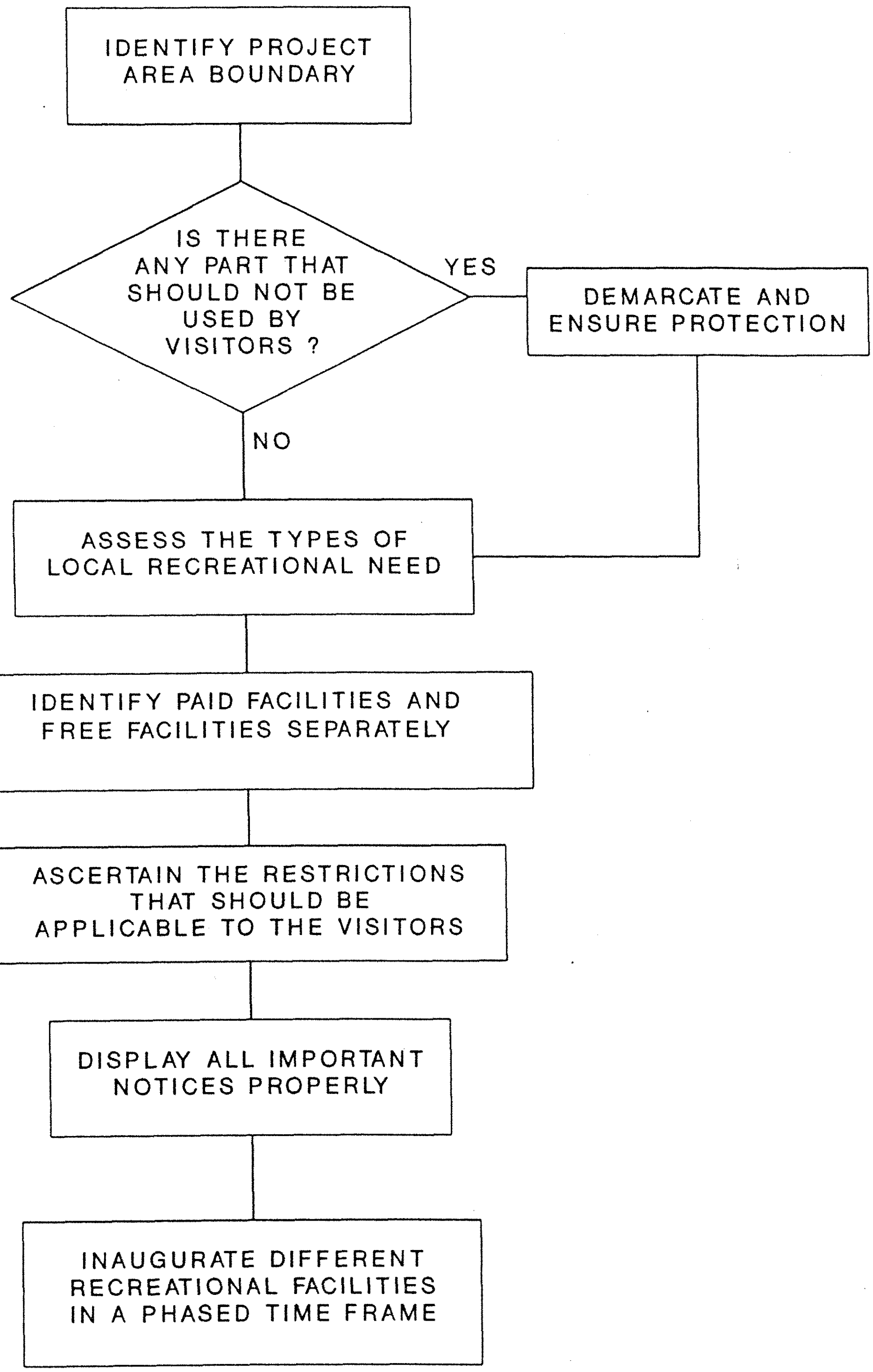


Figure - 22

Enhancing Diversification

Although pisciculture is the mainstay of IWS projects, a diversification by growing crops, vegetables and flowers as also by planting trees ensures economic and ecological sustainability.

As soon as the project is commissioned it will be appropriate to examine the local food habits, market and sources of supply. This will help in choosing the crops. A detailed knowledge of user regions will further assist to clearly identify the cropping options. This will however be possible after sufficient information on the basic ecological features of the user regions is obtained.

It is also necessary to identify the beneficiary families and know their present earning status. This is necessary to compare the relative changes that may take place on account of the IWS project facilities. In some cases it may also be necessary to improve the skill or the capability of the beneficiary or user families for adopting more efficient technology or cultural options.

Steps for diversification in terms of products and species, in addition to aquaculture, are described in the following flow diagram (figure - 23):

STEPS FOR DIVERSIFICATION IN TERMS OF PRODUCTS AND SPECIES IN ADDITION TO AQUACULTURE

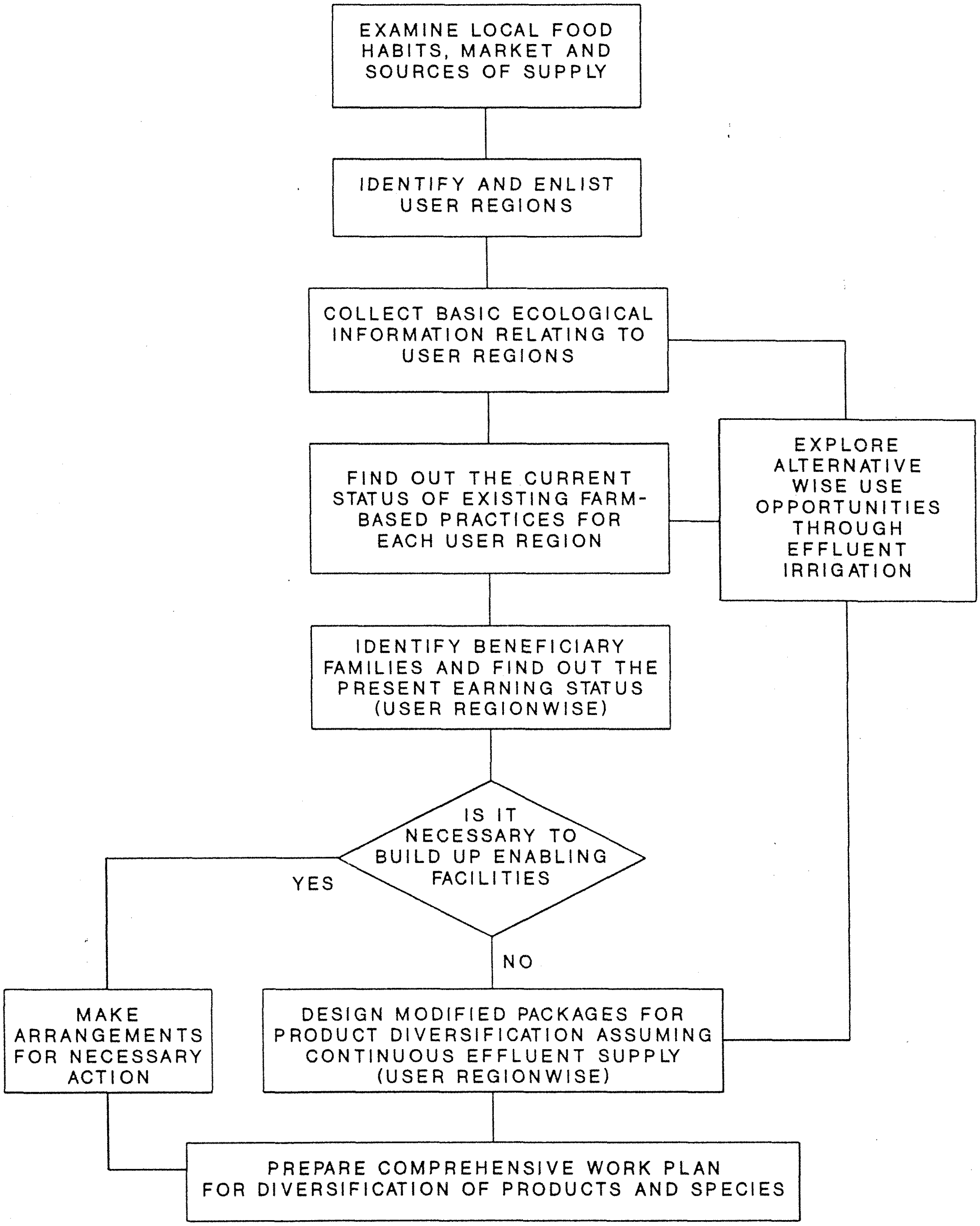


Figure - 23

Yield Development

Conventional practices of pisciculture as well as the related agricultural institutions have laid adequate guidelines for development of fish yield and of other agricultural crops. However, development of fish yield in wastewater ponds does not have any standard guideline. It is therefore necessary to introduce special yield development programme in IWS projects and find out new methods and an improved cultural plan.

It may also be necessary, in many cases, to organize training programmes for fish farmers and associate them with fishery biologists having sufficient knowledge and experience in wastewater aquaculture.

Sequence of activities for yield development programme is shown in the following flow diagram (figure - 24).

STEPS FOR YIELD DEVELOPMENT PROGRAMME

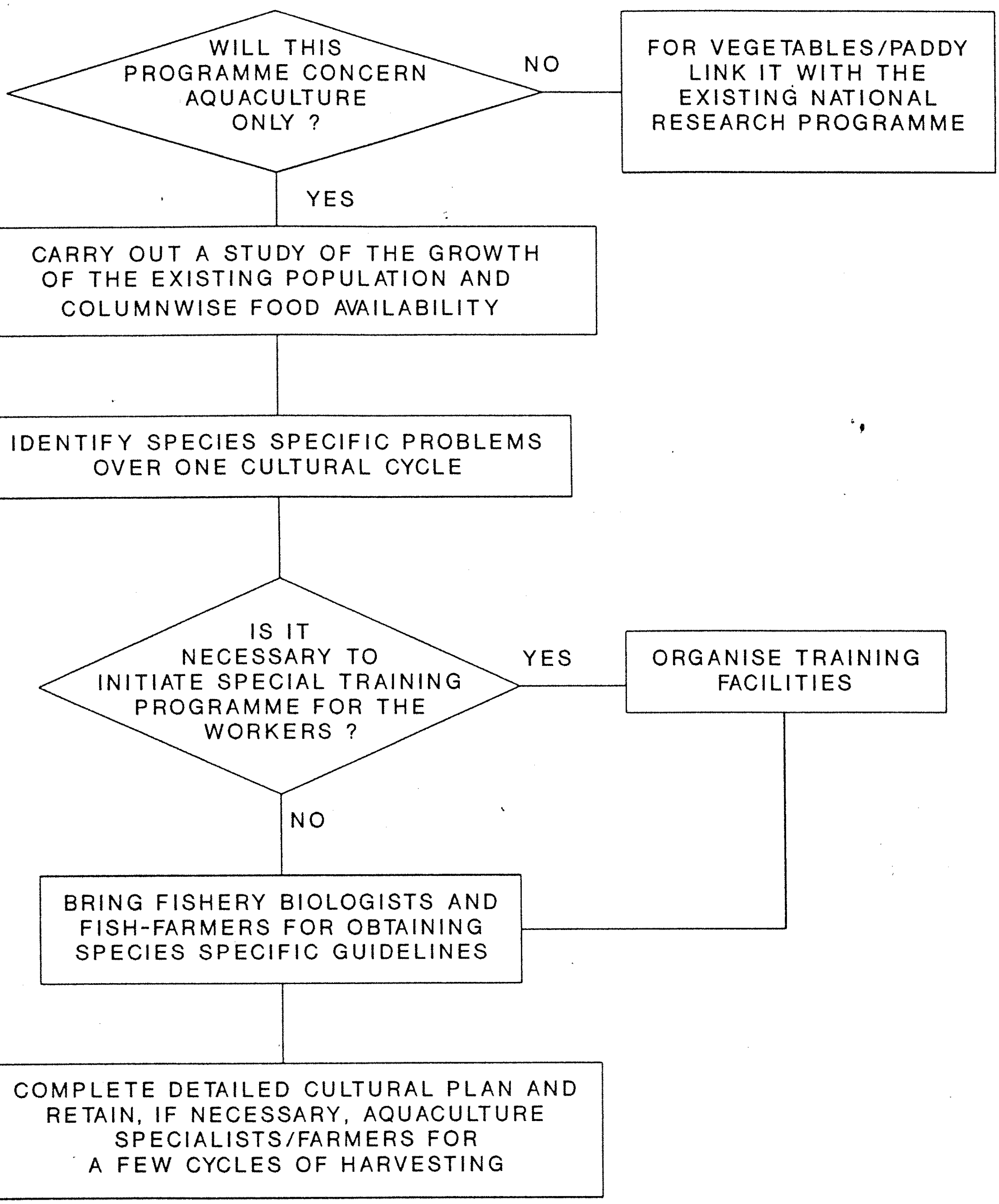


Figure - 24

Conflict Resolution

Five major areas of conflict situation can be anticipated. They have been primarily drawn from the experience of using wetland systems for wastewater treatment and recycling in India. They are :

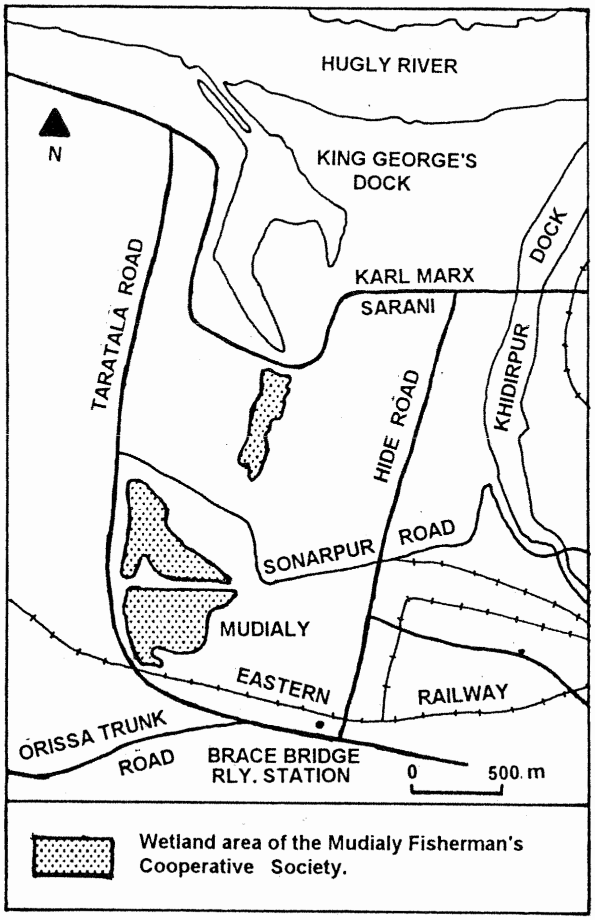
* conflict arising from disagreement regarding effluent distribution,
* conflict arising from workers' non-cooperation,
* conflict arising out of indisciplined activities of the visitors and the local people,
* conflict arising from a lack of proper financial accounting and
* conflict arising from to political interference or indifference.

In most cases, common sense and pragmatism help in a big way to avert or resolve most of the conflict situations. The task will be easier if the project authorities are kept in readiness to foresee the conflict and to take pre-emptive steps.

Absence of proper protection can reduce the marketable size of fish. Such situations should be avoided.

6.3 PROJECT EXAMPLE : MUDIALY CO-OPERATIVE

Drawing support from the experience of the wetlands of eastern Calcutta, the Mudialy Fishermen's Co-operative Society (MFCS) have been successful in transforming a waterlogged area into a resource recovery ecosystem in the south-western fringe of the city of Calcutta and in demonstrating the sustainability of wetland option for wastewater treatment and resource recovery (figure - 25).



BRACE BRIDGE WETLANDS

Figure - 25

About a hundred members of the MFCS produce about 5.6 tonnes of fish per hectare per year from about 50 hectares of water area which once was a 'wooded area'. In the process about 23 million liters per day of composite sewage is treated in the wetlands. The entire ecosystem has been built without any external financial help. The money earned from the sale of fish has given a gross per capita income of about US$3.00 per day which is more than three times the minimum daily agricultural wage in India. Municipal sanitation anywhere, in similar setting, need not be a facility for which the government will have to apportion public money to run the system. For those who will take decision in planning for municipal sanitation, urban and regional development and for cleaning a polluted river, a quick glance at the MFCS experience may not be out of place.

Spawns are being introduced in nursery ponds.

The Pond System

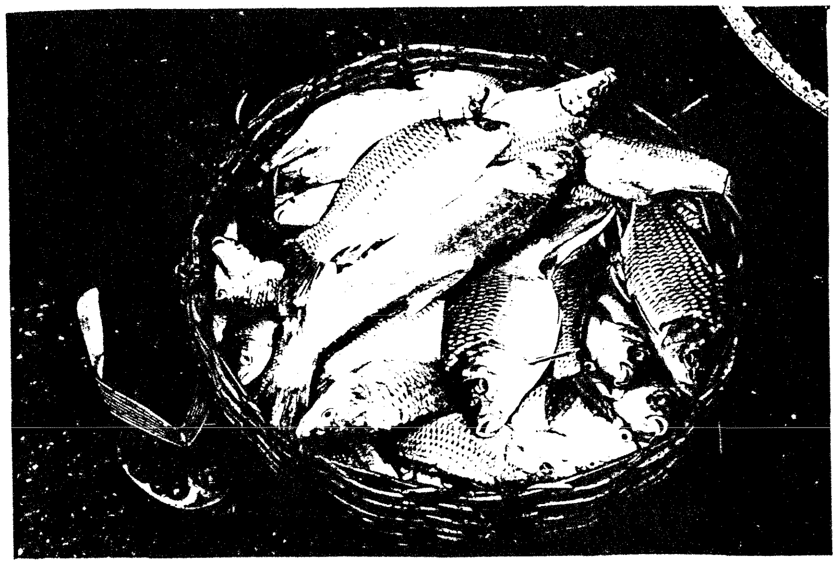
At present 23 Mld of sewage flows through about 50 hectares of waterbodies (Table no. - 7 & 8). There are 15 ponds of various sizes in the MFCS wetland area. Of these, 9 smaller ponds are used for improving the water quality before it enters the bigger ponds where fishes grow and further improvement of water quality takes place. All these ponds have interconnecting culverts and finally drain out the water into a canal which leads to the river Hoogly. Unlike the barren landscape of the east Calcutta wetlands, where trees are scarce, a dense trail of organized plantation makes the area as one of the most sought after open spaces in the region. During 1985 to 1989 about 1,00,000 saplings have been planted on the pond dykes of which 60% have survived.

Growing Fish

Presently, more than one species of fish have been found in some of the ponds which are known to be freshwater varieties of sensitive nature and do not endure the toxic stress which carps and tilapia do. These species are Chanda (Chanda ronga and Chanda nama), Mourala (Amblypharyngodon mola), and Punti (Puntius sophore and Puntius conconius), and these are positive indicators of the level of improvement of the quality of water that takes place in the pond system. Nevertheless, the dominant culture in all the ponds is that of carp and tilapia.

It has been found that there is a direct relationship between the extent of purification of wastewater and density and variety of plankton. Stocking density and variety of fish cultured are also related to the quality of water. While air-breathing fish are found to survive in the ponds nearer to the inlet, carps, prawn and other more sensitive species grow in subsequent ponds far from the inlet. It has also been found that yield of fish is highest in the terminal pond called the Loha jhil, near the outlet (7.80 tonnes per hectare per year) in comparison with 7.00 tonnes per hectare per year, 4.93 tonnes/hectare/year and 3.54 tonnes/hectare/year in the Khudi-1, the Taltala, and Khudi-2 and Khudi-3 jhils respectively.

Common carps are one of the most effective species in wastewater ponds



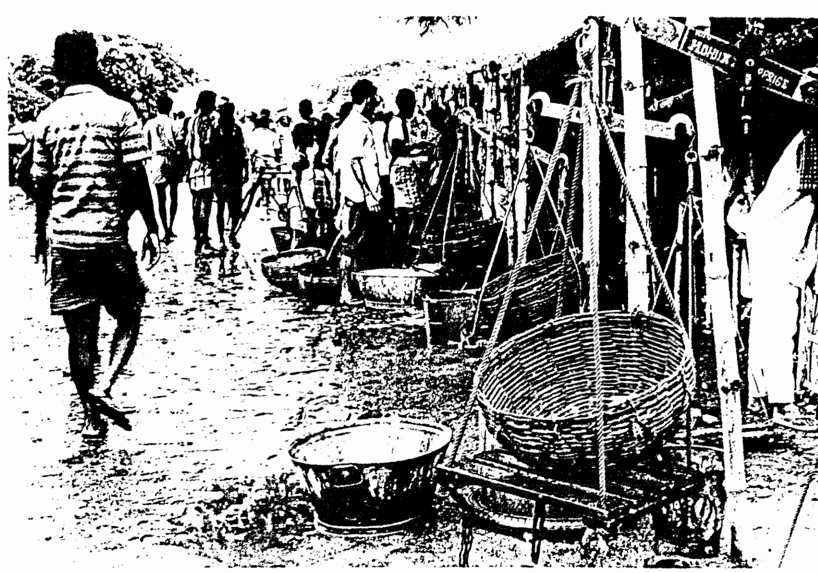
Income Expenditure

Not many co-operative societies, anywhere, will be able to show a standard of book-keeping as efficient and candid as that of the MFCS. A striking feature of income distribution is the near total absence of skewness and if anything has contributed to the growth in earning it is the hard labour of the members. It is no wonder that the highest earning member gets no more than 3.5 times the wage earned by the lowest earning member of the society. Earning from fish sale is phenomenal. Total earning from sale is stepping up each year since the introduction of sewage into the ponds has first began. In 1986 The return from sale of fish was about US$2000.00. It has increased one and a half fold in 1989. There is also a monthly variation in the earning pattern (Table - 9).

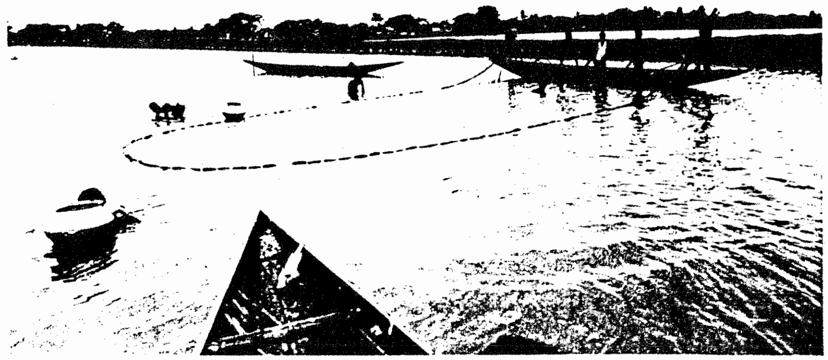
Environmental Education

It is an unforgettable experience to those to have listened to the routine demonstration lectures of the farmer members of the MFCS. It is a pleasure to appreciate their level of understanding the ecosystem and its problems . The plan here, is to develop a 'tutorial ecosystem' for various levels of learners - from children to the decision makers. An information centre has been built that houses seminar rooms, laboratory and a small museum. Display boards are visible in discernible numbers, with a clear intention of raising environmental awareness. However the

There are different kinds of harvesting technique.



A typical auction market where fish is sold.



Various stages of harvesting in wastewater ponds of the Calcutta wetlands.

most important aspect is the variety of life forms that co-exist in a unique assemblage of plants and animals - a facility that is fading very fast from the congested metropolitan cities like Calcutta.

Up-to-date surveys reveal that there are more than 120 varieties of birds coming to these waterbodies of which 27 are migratory. There is also a variety of microflora in the region. There is an enclosure where about 20 spotted deer (Axis axis) are kept. There is also an uncounted but long list of insects, snakes and similar life forms in the wetland area.

The scope for carrying out research in treating wastewater in a pond system and growing fish, is endless. 'Better' designs will definitely come on the basis of a clearer understanding of the ecosystem kinetics. This however need not debar us from taking up 'good' designs right now. The example of the MFCS can be simulated elsewhere having similar environmental conditions. It has enough information to motivate an interested planner to think for his own municipality and to think in terms of transforming a lowlying marsh on the edge of the city into an ecosystem of self-help sanitation.

Table No. 7 WASTEWATER QUALITY IN THE MFCS POND SYSTEM

PARAMETERS	INFLUENT WATER	EFFLUENT WATER
Flow $m^3 . hr^{-1}$	993.3	947.0
Temp^{o}C. Amb/water	30/28	33/28
pH	7.95	7.50
Total Solids	1152.01	788.00
Suspended Solids	51.18	73.00
Dissolved Solids	1099.90	715.00
Total Voltile Solids	340.41	210.00
BOD	77.58	15.00
COD	470.42	65.00
Total Alkalinity as $CaCo_3$	285.44	192.00
Total Nitrogen as N	114.07	31.00
Phosphate as P	0.20	0.04
Mercury as Hg, $g.l^{-1}$	4.52	Below Detectable Limit

All parameters except pH, Temperature, Mercury and Flow are expressed in $mg.l^{-1}$.

Table No. 8 REMOVAL OF BOD AND COLIFORM IN THE MFCS POND SYSTEM

	INFLUENT WATER	EFFFLUENT WATER	% OF REMOVAL
BOD ($mg.l^{-1}$)	77.00	15.00	80.52
Fecal Coliforms (MPH/100ml x 10^3)	46000.00	0.91	99.9980

NEERI, 1990. Water Quality Studies Of The Jeel In Calcutta Port Area. National Environmental Engineering Research Institute, Nagpur, India, p.35 & 75.

Table No. 9

Source : MFCS Records

MONTHLY EARNING FROM FISH SALE

(In Rs.)

YEAR	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APRIL	MAY	JUNE	TOTAL
1980-81	42346	49517	41312	52528	57509	61601	54146	47301	41537	51201	103621	195842	798461
1981-82	91013	70117	88309	76201	69212	86301	85151	83985	79546	87243	97241	106993	1021412
1982-83	98306	67576	69307	112503	107202	78507	76594	91322	87507	134509	137564	157028	1217525
1983-84	125220	68212	96155	94201	95907	72301	74506	90442	88336	107109	195211	202477	1310077
1984-85	86422	60501	123222	98451	42221	69340	86937	92301	75405	97485	132982	223208	1188833
1985-85	88420	62536	72228	122987	45887	85803	84423	79383	76235	101395	165704	324269	1309275
1986-87	372176	428828	266926	265506	205651	180070	184898	165021	193459	205589	352592	609855	3429926
1987-88	408341	425199	375536	280583	290096	148594	80960	101625	240970	260670	352067	537004	3501606
1988-89	253949	310524	284934	304986	223241	206067	205676	162765	165064	289872	489957	883682	3902625
1989-90	452627	518942	488851	530211	453672	375026	296190	365645	411293	292283	355235	460952	5001441

$1.00 = Rs.19.00

ANNEXURE - I

WHAT IS A WETLAND ?

General configuration of the earth's surface presents areas of depressions, level lands, and mounds. These occur as both large scale and small scale features. The depressions are, naturally for the most part, covered with water, either temporarily or permanently. Wherever they are not, either physical or human factors would be found responsible. Wetlands are parts of the earth's surface between true terrestrial and aquatic systems. Thus shallow lakes, marshes, swamps, bogs, dead river beds, borrow pits, are all wetlands irrespective of their extent, duration of flooding, climatic regions in which they exist, their water quality and degree of human interventions. A distinction is, however, made between wetlands and deep water habitats including deep lakes. Wetlands are generally shallow and are thus differentiated from deep waterbodies. The former is frequently found to comprise the fringes of the latter.

Wetlands have one unique characteristic of presence of water and a water saturated soil. This may again be either a permanent feature or occurring for a part of the year. During the wet period, they should support hydrophytes. This ecosystem is a transitional zone between the dry terrestrial and wet aquatic systems, having characteristics of both the systems, as well as some of its own which are unique. Diversity of character, size, type and mode of occurrence of wetlands have given rise to different indices of describing them and it should be noted that wetlands have been defined from time to time to suit a particular location and such definitions could be extended and applied to other regions also. However, a universal definition of wetlands has yet not been established (Trishal & Zutshi, 1985). According to Mitsch & Gosselink (1986), the wetlands often include three main components. These are presence of water, unique soils differing from those of uplands and presence of vegetation adapted to wet conditions. Some of the commonly accepted and used definitions are mentioned hereunder (Mitsch & Gosselink, 1986).

Circular 39 Definition : It is one of the earliest definitions of wetlands given by US Fish & Wildlife Service in 1956. It states that - The term *'wetlands'* .... refers to lowlands covered with shallow and sometimes temporary or intermittent waters. They are referred to by such names as marshes, swamps, bogs, wet medows, potholes, sloughs, and river - overflow lands. Shallow lakes and ponds, usually with emergent vegetation as a conspicious feature, are included in the definition, but the permanent water streams, reservoirs, and deep lakes are not included. Neither are water areas that are so temporary as to have little or no effect on the development of moist-soil vegetation.

Canadian Wetland Definition (1979) : This is used in the Canadian Wetland Registry which is the data bank and inventory of Canadian

Wetlands. It states that - Wetland is defined as having the water table at, near or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophylic vegetation, and various kinds of biological activity which are adapted to the wet environment.

Fish & Wildlife Service Definition (1979) : This definition is so far the most comprehensive one and states that - Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water ..... Wetlands must have one or more of the following three attributes : (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is with predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year. This is the most widely accepted definition in the United States to day.

A Legal Definition was given by the **US Army Corps of Engineers** for implementation of dredge and fill permit system required by Section 404 of the 1977 Clean Water Act Amendments.According to the definition the term *'wetland'* means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas (33 CFR 323.2 (c); 1984).

The Ramsar Convention Definition : The 1971 Ramsar Convention defines wetlands as (Maltby, 1986) - areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.

I.B.P. Definition (1972) : This definition considers the wetlands as (Trishal & Zutshi, 1985) - parts of the surrounding ecological structure and as seral stages in the succession from open water to dry land or vice-versa, occurring at sites situated as a rule between the highest and the lowest water levels, as long as the flooding or waterlogging of the soil is of substantial ecological significance.

With the amount of scientific thinking and research that are now being fed into the study of this ecosystem and its management, it is no wonder that we may see more appropriate definitions coming in future. Common people, who in fact draw their sustenance from wetland resources, are in many cases, objects of study for us for incorporation in the definition.

WETLAND CLASSIFICATON :

Classification of wetlands have been made from time to time, each differing from the other in basis and other objectives. In the US and Canada some of the earliest classifications were undertaken on the basis of how they could be drained for the human use. Later the objective was to compare different wetlands for their value to waterfowl. At present the classifications are centred on multiple ecological values of wetlands (Mitsch & Gosselink, 1986). Thus we find the classification or choice of grouping attributes of an ecosystem changes according to the need of the work i.e. inventory, evaluation and management. Objectives of wetland classification can be :

* grouping wetlands with similar vegetation type, plant or animal species, hydrologic conditions, mode of formation etc. analogous to taxonomic classification done by the life scientists.

* grouping of functionally valuable wetlands.

* grouping of wetlands for providing compatibility for inventorying, mapping, concepts and terminology necessary for wetland management. This is mainly for spatial comparison and understanding of different wetlands in different regions.

It is therefore obvious that we have to decide upon or perhaps determine a new basis of classification to suit the purpose of management of wetland resources. A summary of the existing the classification of wetlands are given in the following table.

Reference		Year	Done by	Basis of Classification	Classification
Peatland Classification	Michigan bogs of USA	1907	Davis	i. Landform on which the bog was established. ii. Process of formation. iii. Surface vegetation.	
Circular 39 Classification	An early wetland Classification published in US Fish & Wildlife Circular No. 39	1956	Shaw & Fredine	1. Increasing water depth & frequency of inundation. 2. Life forms of vegetation. 3. Salinity.	Four major categories are: 1. Inland fresh areas. 2. Inland saline areas. 3. Coastal freshwater areas 4. Coastal saline areas. With 20 wetland types with site characteristics.
Classification of Natural Ponds & Lakes in the Glaciated Prairie Region	Prairie Potholes of upper Midwest USA	1971,72	Steward & Kantrud	1. Vegetation zones occupying deepest portion of each pothole basin. 2. Hydrologic characteristics of vegetation zones. 3. Variations in salinity for	1. Ephemeral Ponds. 2. Temporary Ponds. 3. Seasonal Ponds & Lakes. 4. Semipermanent Ponds & Lakes. 5. Permanent Ponds & Lakes. 6. Alkali Ponds & Lakes. 7. Fen (alkaline bog) Ponds. With 6 subclasses and four cover types.
Hydrologic Classification of European Peatlands		1974	Moore & Bellamy	Flow-through conditions of groundwater	A. Rheophilous mire - Peatland influenced by groundwater derived from outside the immediate watershed. B. Transition mire – Peatland influenced by groundwater derived solely from the immediate watershed. C. Ombrophilous mire.

Reference		Year	Done by	Basis of Classification	Classification
Coastal wetland classification	USA	1974	H.T. Odum, Copeland & McMahan	1. Forcing function e.g. seasonal programming of sunlight & temperature. 2. Stresses such as ice.	A. Naturally Stressed Systems of Wide latitudinal Range. B. Natural Tropical Ecosystem. C. Natural Temperate Ecosystems with Seasonal Programming. D. Natural Artic Ecosystem with Ice Stress. E. Emerging New Systems Associated with Man.
Classification of Forested Wetlands in Florida	USA	1976	Wharton et al.	1. Hydrologic inputs.	1. Cypress Ponds (domes) – Still water. 2. Other Non-stream Swamps. 3. Cypress Strand – slowly flowing water. 4. River Swamps and Flood Plains. 5. Salt Water Swamps – Mangroves.
Classes and subclasses for Freshwater Wetlands in the Glaciated N. En United States.		1978	Golet & Larson	1. Life Forms. 2. Wetlands have also been defined & categorised on the basis of size, site types, cover types, vegetative interspersion types & surrounding habitat types.	1. Open Water with 2 subtypes. 2. Deep Marsh with 6 subtypes. 3. Shallow Marsh with 4 subtypes. 4. Seasonally Flooded Flats with 2 subtypes. 5. Meadow with 2 subtypes. 6. Shrub Swamp with 4 subtypes. 7. Wooded Swamp with 2 subtypes. 8. Bog with 2 subtypes.
Classification of Wetlands on a Hydrodynamic Energy Gradient	USA	1978	Gosselink & Turner	1. Source of water. 2. Velocity of waterflow. 3. Frequency of flooding.	1. Raised–Convex systems. 2. Meadow. 3. Sunken – Concave. 4. Lotic. 5. Tidal. 6. Lentic.

Reference		Year	Done by	Basis of Classification	Classification
	Indian Subcontinent	1978	Trisul, Zutshi. Kaul, Trisal ar 1 Handoo. Based on: Champion & Seth (1968)	Vegetation type	1. Herbaceous wetlands. i. Tall growing emergents with shoots more than one metre. ii. Low growing emergents with shoots between 25 cm to 100 cm. iii. Ground layer species with shoots less than 25 cm. Dominated by emergents, rooted floating leaf types and submergents. 2. Forested wetlands. 1. Littoral forests. 2. Tidal swamp forests. 3. Fresh-water swamp forests. 4. Seasonal swamp forests. 5. Riverine fringing forests.
Classification of Wetlands and Deepwater Habitats of the United States.		1979	Cowardin et al.	1. Hydrologic characteristics. 2. Geomorphology. 3. Chemical character. 4. Biological factor, including dominant vegetation. 5. Substrate type.	1. Marine. 2. Estuarine. 3. Riverine. 4. Lacustrine. 5. Palustrine. With 8 subsystems, 11 classes, 23 subclasses and also with water regime, salinity and soil material modifiers and dominance types of flora & fauna.
	Indian Subcontinent	1985	Trisal & Zutshi	Mode of formation.	1. Naturally occuring waterlogged areas including lakes and flood plains of rivers 2. Man-made wetlands including large number of ponds, small lakes and shallow depressions filled with water for varying length of time in a year and supporting typical marsh vegetation.

Source : Mitsch & Gosselink, (1986) and Trisal & Zutshi, (1985).

ANNEXURE - II

CARRYING WASTEWATER TO THE IWS SYSTEM

Wastewater from a city can be carried upto the IWS system by three methods viz. (i) gravity flow, (ii) pumping or (iii) by a combination of both. Normally, the combined system is not recommended any more. For all types of sewer a design period of 30 years is recommended. Wastewater can be collected by means of :

a) separate sanitary sewer and storm sewer
b) combined sewers

Sanitary sewer is not expected to receive storm water. However, in an ordinary sewerage system it may not possibly be avoided. Where the storm sewage is carried through an entirly seperate system, the total capacity of the sewerage system may usually be designed to take a flow upto four times dry weather flow (d.w.f.) for the region. In a combined sewage, during storms, about six times the dry weather flow is expected and where such a system exists it must be capable of dealing with flows upto that level. Estimates of storm runoff can be made by (i) rational method, (ii) unit hydrograph method or by (iii) overland flow hydrograph method.

A) Gravity Sewer Mains

To design a gravity sewerage system, it is necessary to maintain a minimum velocity or 'self cleansing velocity' in a sewer to ensure that the suspended solids do not get deposited. For sanitary sewers a minimum velocity of 0.8 m/s (at design peak flow) is recommended, subject to a minimum velocity of 0.6 m/s for present peak flows. For avoiding erosion by sand and other gritty materials present in the sewer and also by excessive velocity, the maximum velocity should not exceed 3.0 m/s. The minimum diameter of an underground public sewer should be 200 mm. Factors which influence the selection of the sewer mains are flow characteristics, watertightness, ease of handling, installation and assembling, physical strength, resistance to scour and chemicals etc. The most commonly materials used are brick, concrete (precast or cast-in-situ), asbestos-cement, stoneware or vitrified clay, plastic, cast iron etc. For all types of material, preventive measures for corrosion must be taken.

The required diamater and slope to carry a flow for a particular velocity can be obtained by the well-known Manning's formula. The general expression for flow is :-

$$V = (1/n)\, r^{2/3}\, s^{1/2}$$

For circular conduit, this expression may be modified as :-

$$V = 3.968 \times 10^{-3} (1/n)\, d^{2/3}\, s^{1/2}$$
$$Q = 8.661 \times 10^{-7} (1/n)\, d^{8/3}\, s^{1/2}$$

V = velocity of flow in mps
Q = quantity of flow in m3/hour
d = diameter of pipe in mm
s = slope of hydraulic gradient
r = hydraulic radius in metres
n = Manning's coefficient of roughness

For the present peak discharge and a velocity of 0.6 m/s, the slope and diameter are chosen. For this diameter and a velocity of 0.8 m/s, the discharge at full depth is found out. For ventilation in sewerage flow, sewers should not be designed to run full; for a diameter of upto 400 mm the sewers may be designed to run at half depth; for 400 to 900 mm at two-thirds depth; and for larger sewers at three-fourths depth at ultimate peak flows. The relation between flow ratio and velocity ratio with the depth ratio is given below :-

Hydraulic Properties of Circular Sections

Constant n			Variable n		
d/D	v/V	q/Q	nd/n	v/V	q/Q
1.0	1.000	1.000	1.00	1.000	1.000
0.9	1.124	1.066	1.07	1.056	1.020
0.8	1.140	0.988	1.14	1.003	0.890
0.7	1.120	0.838	1.18	0.952	0.712
0.6	1.072	0.671	1.21	0.890	0.557
0.5	1.000	0.500	1.24	0.810	0.405
0.4	0.902	0.337	1.27	0.713	0.266
0.3	0.776	0.196	1.28	0.605	0.153
0.2	0.615	0.088	1.27	0.486	0.070
0.1	0.401	0.021	1.22	0.329	0.017

Depending upon the diameter the depth ratio is fixed and the corresponding flow and velocity ratios are found. Q is then determined and a check is applied to verify whether or not this exceeds the actual ultimate peak discharge. Otherwise, the next higher diameter or steeper slope is selected and adjusted to satisfy the velocity and flow requirements.

B) Force Mains

Where the sewage is transmitted into the treatment plant by pumping it is to be carried through the force mains. The design of a force main must take into account the head loss imposed by friction, while the choice between different diameters and materials will be partly a matter of economics. Therefore, the size of the main should be determined by taking into account the initial cost of the pipeline and cost of operation of pumps for different sizes of the main. In past, most force mains were made either of cast or spun steel. Many other materials are now available and used regularly, which include mild steel (usually protected inside and outside by bitumen), cement-concrete (reinforced or prestressed), asbestos-cement and plastics.

To design a force main, the popularly used Hazen-William's formula for a pressure conduit is as follows:-

$$V = 0.849\ C\ r^{0.63}\ s^{0.54}$$

For circular conduits, the expressions are :

$$V = 4.567 \times 10^{-3}\ C\ d^{0.63}\ s^{0.54}$$
$$Q = 1.292 \times 10^{-5}\ C\ d^{2.63}\ s^{0.54}$$

Q = discharge in m^3/hour
d = diameter of pipe in mm
V = velocity in mps
r = hydraulic radius in metres
s = slope of hydraulic gradient
C = Hazen-William coefficient

The following values of C (Hazen William coefficient) may be adopted for design purposes :

Material	C
Cast iron	100
Steel	100
Asbestos cement	120
Cement concrete	110
Plastic (smooth)	120

Velocity of flow in the force main, particularly for sewage pumping, is significant. As sewage is pumped at a fairly constant rate through a day, the velocities through force main may range from 0.8 m/s to 3.0 m/s. The most economical diameter of force main has a velocity of flow at normal pumping rates lying between 0.8 m/s to 1.2 m/s and a velocity at maximum rates of pumping of not more than about 1.8 m/s.

Moreover, with sewage, the length of time between discharge to the wet well of the station and the ultimate discharge at the end of the force main is important, because if this time is too long, the sewage may become septic. The time must be calculated on the basis of the existing flows and not on the increased flows that are likely in future. If the duration becomes more than 12 hours, a revision of the proposal and design of the force main will be necessary.

C) Pump House

The ideal site for treating sewage is at or near the lowest point of the sewerage system so that all sewage will flow to it by gravity. This is, however, rarely possible and there will normally be low isolated areas where sewage can accumulate and from where it must be pumped into the treatment plant. The pumping station should be located and costructed in such a manner that it will never be flooded and in the event of power failure or heavy storm an overflow is possible.

The capacity of the station will be determined by the present and future sewage flows based on a design period of 15 years. The capacity of the pump should be adequate to meet the peak rate of flow with 50% standby. The number and size of units for larger pumping station will be so selected that the variation of inflow can be handled by throttling of pumps without starting and stopping of pumps too frequently.

A sewage pumping station will usually be designed to have a pumping capacity of upto 6 times the dry weather flow. The dry weather flow should take into account the flow of domestic sewage plus infiltration, together with the flow of industrial wastes. The rates of flow are generally those which occur after a period of 6 to 7 consecutive days of dry weather during which rainfall has not exceeded 0.25 mm. Where the storm sewerage is entirely a seperate system, pumping capacity of four times d.w.f. is justifiable. Where the sewerage system is not strictly seperate, the pumping station must be capable of dealing with flows of upto at least six times d.w.f. When the sewerage system is combined, a flow considerably in excess of 6 times d.w.f. can be expected during storms. If pumps are installed for a flow upto 6 d.w.f., provision must be made for the excess flow to be diverted to one or more storm sewage overflow channels. But above all, in case of combined sewerage, it is always better to calculate the exact storm run-off with the help of the methods mentioned in the text and design the capacity of the pumping stations accordingly.

Pumping stations are provided with two kinds of well : wet wells for receiving the incoming sewage and dry wells for housing the pumps. The wet and dry wells may be of any of the following types :-

(i) Rectangular, with dry and wet wells adjacent to each other.
(ii) Circular, with central dry well and peripheral wet well.
(iii) Circular, with a dividing well to seperate the dry and wet well.

The arrangement of the wet well will depend on the types of pump being installed. Ususally the vertical-spindle pumps are installed in the dry well alongside the wet well, with suctions taken through the dividing wall. When submersible pumps are installed, they should be in the wet well, while the motors should generally be mounted on a floor vertically above. Horizontal spindle pumps are cheaper in capital cost, but these are not normally practicable, particularly when the sump is deep. Vertical spindle units occupy less floor space so that the cost of construction of the pumping station is less. However, it is difficult to install and maintain them when compared with horizontal units. Horizontal spindle installation would usually entail considerably more excavation for pump and motor, and there is an added possibility of the motor being damaged in the event of an overflow of water entering the pump chamber.

Pumps can be of four broad categories :-

(a) centrifugal pumps,
(b) reciprocating pumps,
(c) pneumatic ejector pumps and
(d) screw pumps.

The use of reciprocating pumps is now generally limited to the smaller installations as they are suitable for crude sewage. They are available for flows upto about 15 to 20 litres/sec. Nowadays they are replaced by centrifugal pumps. The pneumatic ejector pumps are used in case of smaller installations where the centrifugal pumps are too large for the purpose. These types are effective to pass very low flows and at the same are suitable for liquids containing solids upto 100 mm diameter. They are most suitable for moderate heads (not more than 30 meters) and for flows from about 3 m^3/hr to 30 m^3/hr. Sewage is commonly pumped by centrifugal units. When large volume of flow must be moved against low to moderate heads, as in pumping storm sewage from a leeved area, centrifugal pumps are used. Centrifugal pumps can be classified as :

(i) axial flow pump,
(ii) mixed flow pump and
(iii) radial flow pumps.

The classification is usually based on the specific speed at the point of maximum efficiency. Axial flow pumps develop most of their head by the propelling action of the impeller vanes on the liquid. The head developed by a mixed flow pump is partly through centrifugal action and partly by lift of the impeller vanes on the liquid and that developed in radial flow centrifugal pump is principally by the action of centrifugal force. The salient features of the three types are as follows :-

Characteristics	Axial Flow	Mixed Flow	Radial Flow
Usual capacity range (litres/min) (cu.m/hour) (cu.m/sec)	 4500-900000 >2000 >0.5	 1000-450000 >100 >0.05	 25-225000 all all
Head range (m)	1-11	3-30	6-50
Efficiency	76%-85%	80%-90%	60%-90%
Speed (rpm)	200-1600	200-4000	400-4000
Kilowatt characteristics	Decreases with capacity	Flat	Increases with capacity
Suction lift	Usually requires submergence	Usually requires submergence. Short suction lift is permitted	Usually not over 4.5
Service	Used where space and cost are considerations and load factor is low	Used where load factor is high and where trash or other solid matter is encountered	Used where load factor is high and high efficiency and ease of maintenance are desired

Conventional sewage pumps are most common ones used for handling raw sewage. A conventioal sewage pump is more specifically described as an end suction, volute type centrifugal with an overhung impeller of either the non-clog or the radial or mixed flow type, depending on capacity and head. Pumps should be selected on the basis of their maximum efficiency at average operating conditions. The capacity of pumps should be adequate to meet the peak rate of flow with 50% standby. However, the pumping installations are usually built in such a way that their firm capacity is either equal to the maximum total inflow rate of the incoming sewers or can be increased to accomodate this level. It is customary to provide a total pumping capacity equal to the maximum expected inflow with at least one of the largest pumping units out of service. A minimum of two pumps should be installed, where the maximum inflow is less than 150 cu.m/h. At larger installations, the size and number of units should be such that the range of inflow can be met without starting and stopping pumps too frequently and without requiring excessive wetwell storage capacity. Variable capacity pumps can be used to match pumping rate with inflow rate. When the variable capacity pumps are used, a minimum of two units should be installed. In those cases, where more than one variable-capacity unit are required to handle peak flow, three units should be installed. In this manner, it is possible to maintain a reasonable rate of flow through each pump. In case of power failure, a diesel standby unit should be provided at the pumping station, to meet the requirements. Very small and less important pumping stations may not require this standby arrangement.

Usually the centrifugal pumps are completely filled with the liquid to be pumped before starting. When so filled, the pump is said to be primed. Pumps operated with a suction lift may be primed in several ways, (i) with a special type of check valve, called a foot valve, (ii) a better method is to close a valve in the discharge line and prime by evacuating air from the highest point of the pump casing.

Non-clog pumps have impellers which are usually closed and have, at most, two or three vanes. The clearance between the vanes is generally sufficiently large so that anything which will escape the pump suction will pass through the pump. Suction and delivery openings of the pumps should not be less than 100 mm and the pump should be capable of passing a ball of at least 80 mm diameter. A bladeless impeller, sometimes used as a fish pump, has also been applied for pumping sewage. For a given capacity, bladeless impellers are larger than vane designs.

For moderate climates, the maximum suction lift can be set at about 6.0 m. To determine whether the pump is safe or not from cavitation effect, one should calculate the Net Positive Suction Head (NPSH) of the pump. NPSH is the difference between the static pressure and the vapour pressure of the liquid at the pump inlet flange. There are two NPSHs that a system designer must consider. One is the NPSH Available (NPSHA), which is dependant on the piping system (most importantly on the relative elevation of the pump and the source of liquid being pumped). The second is NPSH Required (NPSHR) by the pump selected for the service. The task of the system designer is to ensure that the NPSHA exceeds NPSHR.

The maximum speed at which a pump will operate is determined by the NPSHA of the pump, the quantity of liquid being pumped and the total head. The head on the pump will consist of three elements :

(i) the suction lift,
(ii) the delivery head and
(iii) the friction losses.

In general, it is not a good practice to operate sewage pumping units at a speed in excess of 1750 rpm. This is again applicable to smaller units only. Larger pumps should operate at a lower speed. A term similar to that for pump specific speed has been developed for pump inlet characteristics and has been identified as suction specific speed S. The value of S is expressed simply as a number and for general purpose pumps, does not exceeds 194 in the metric system. The pump selected for a fluid system must deliver the specific flow and required head at or near the pump's maximum efficiency, and should have a NPSHR less than NPSHA. The first step in pump selection is to contact several pump manufactureres and obtain performance curves of the pumps they recommend for specific service. To simplify the process, it is customary to plot, for any given speed, the performance curves to show pump characteristics over the available range of impeller diameters rather than at single diameter. This curve data should show the flow, head, efficiency, power and NPSHR for a variety of impeller sizes (diameter). Such curves will vary widely in their nature with changes in Ns (specific speed), and an understanding of these variations is essential for the selection of properly sized pump drivers and in many cases, for proper design of discharge piping and/or the determining the limiting ranges of pump operation. Pump size should also be coordinated with wet well design in order to avoid frequent on-off cycling of pumps. Standard motors should not be run more than six times an hour. Selection of motor size is also an important parameter. It is to be noted that there is a minimum power that the pump will require regardless of flow. It is advisable to use a motor with a power rating at least equal to this maximum power required, since, in most applications, there will be times when the pump is called upon to deliver higher flow rates than are originally expected.

Septicity can be prevented or minimised by reducing the time taken for a sewage to reach the treatment works, particularly by reducing delays at pumping stations and in rising mains. Inflow into wet
well without pumping should not exceed about 30 minutes if septicity is to be prevented. Other remedial measures adopted from time to time include aeration of the sewage and addition of chlorine, lime etc.